AN ANALYSIS OF FOOD HABITS OF GREEN-WINGED TEAL, NORTHERN PINTAILS AND MALLARDS WINTERING IN THE SUISUN MARSH TO DEVELOP GUIDELINES FOR FOOD PLANT MANAGEMENT

A Report to the California Department of Water Resources
and the United States Bureau of Reclamation

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Balboa	California Farms	Can-Can
Cygnus	Delta King	Greenhead
Grizzly Farms	Gum Tree	Horseshoe
Island Club	Joice Island Mallard Farm	Montezuma
Morrow Island Land Co.	Pintail Ranch	Rich Island
Sprig Farm	Sunrise Island	Teal Club
Tip End	Tree Slough	Tule Farms
Wingnuts	Windsong	

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The last diet study conducted in the Marsh was nearly 40 years ago. To some this may seem too long a spell, but to the legions of U.C. Davis undergraduates who spent so much of their carefree college days in a windowless lab peering through microscopes at thousands of seeds and bugs, well, they might recommend 100 year intervals between diet studies. There are too many to name them all, and some lasted only a few hours, days, or weeks. The few studious souls who exhibited a patience and attention worthy of mention are Jeff Akiyoshi, Rob Wolfson, Tara Von Dollen, Danika Tsao, Tami Lim, Heidi Kirk, and Jen Waggoner. We only hope their laboratory experiences didn't drive them away from careers working with wildlife; their perseverance and humor are rare and requisite qualities in any wildlife biologist.

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BACKGROUND AND RATIONALE

California is the most important waterfowl wintering region in the Pacific Flyway (Bellrose 1980). The number of ducks wintering in the state range from 3-6 million, and under normal conditions, nearly 60% of all Pacific Flyway waterfowl winter in California (USFWS 1978). California's most important wintering waterfowl region is the Central Valley. This vast area of over 4,000,000 ha (10,000,000 ac) consists of the Sacramento and San Joaquin Valleys, joined centrally by the Sacramento-San Joaquin River Delta region (Delta), which includes the Suisun Marsh (Marsh). The largest proportion of wintering waterfowl are found in the Sacramento and San Joaquin Valleys, but waterfowl are also abundant in the adjacent Suisun Marsh. In the past, the Suisun Marsh held nearly 30% of all waterfowl present in California during early fall. However, recent counts (Becker, unpubl. data), have documented a marked decline in numbers of ducks using the Marsh, especially northern pintails (*Anas acuta*), which have been decreasing since the 1960's (Michny 1979). The reasons for this decline are not clear, but possibilities include changing agricultural practices in the Delta and Central Valley (Michny 1979) or effects beyond the wintering grounds, such as impacts to key breeding areas (Greenwood et al. 1995). Additionally, numbers of resident mallards, many of which breed in the Central Valley and Marsh, declined to their lowest surveyed numbers since 1990 (CWA, 2002, unpubl. data).

Waterfowl are present in large numbers in Suisun Marsh from early September to March and require food resources to meet their energetic and nutritional demands. Food habits studies have long been the starting point for understanding the details of wildlife energy demands, including selection relative to the timing and abundance of food items (Martin et al. 1961, Litvaitis 2000). Existing food habits information for ducks using the Suisun Marsh is outdated (George et al. 1965), and more recent studies have revealed critical methodological and analytical improvements.

George et al. (1965), used gizzard samples to examine the food habits of several duck species in Suisun Marsh, and Mall (1969) related soil and water salinities to the growth of these important duck food plants. These early studies suggested that ducks used the very abundant alkali bulrush (*Scirpus maritimus*) and the relatively uncommon brass buttons (*Cotula coronopifolia*) most heavily of the foods available in the Marsh. However, analyses of diets using gizzard samples have been shown to bias results in favor of hard seeds at the expense of softer foods (Dillon 1958, Swanson and Bartonek 1970). Accordingly the conclusions of early diet studies may be inaccurate. Mall (1969) related food use to availability in Suisun Marsh by comparing percentage composition of plant foods eaten [frequency of the food (% of ducks with the item in their gizzards) x percent volume in gizzard samples], to the percentage ground coverage of the plant in the Marsh. He concluded that waterfowl strongly selected alkali bulrush and brass buttons. However, plant ground coverage does not equate to quantity of food available, especially for seeds (Miller et al. 1975, this study).

Agricultural practices within the Marsh, the Delta and the Sacramento Valley affect waterfowl distribution and habitat use. Studies of waterfowl diets show that even in areas of abundant naturally occurring foods, waterfowl will often feed on readily available, high energy agricultural grains (Hochbaum 1955, Miller 1987). In fact, the Joice Island unit of the Grizzly Island State Wildlife Area (SWA) was first established (1932) to reduce waterfowl damage to cereal grains grown in the Sacramento Valley and Delta (Arnold 1996). Barley was routinely cultivated and left standing for waterfowl food on Grizzly Island SWA until the late 1990's, and often appeared in food habits collections (CDFG unpubl. data). There is some evidence that the reduced use of Suisun Marsh by pintails resulted from a combination of the elimination of barley on the SWA and an increase in corn acreage in the Delta (Michny 1979). Casazza (1995) found that pintails radio-marked in August in the Marsh soon emigrated, and by mid-December, less than 15% of the marked birds remained, with most of them having moved into newly flooded harvested agricultural fields in the Delta. Updated food habits analyses from Suisun Marsh are needed to provide an assessment of the relative importance of foods available in the Marsh versus foods available in the Delta, such as agricultural grains, weed seeds, or foods found in islands managed as freshwater marsh (Miller et al. 1993).

Recent studies of waterfowl feeding ecology, using techniques that do not contribute to bias based on the hardness of food items consumed, have documented food habits of pintails and green-winged teal (*A. crecca*) in the Sacramento and San Joaquin Valleys (Beam and Gruenhagen 1980, Connelly and Chessmore 1980, Miller 1987, Euliss and Harris 1987). These methods have not been applied to Suisun Marsh. Information is needed in the Marsh about the total array of foods consumed relative to their availability during early fall, when many foods are most abundant, and into mid-winter when foods are less abundant due to decomposition and depletion by waterfowl and other wildlife.

The lack of such information is critical because wetland management in the Marsh is predicated upon detailed management plans (Miller et al. 1975, Rollins 1981) based on potentially biased food habits results (gizzard contents). These management plans are based on Mall's (1969) findings that duration of soil submergence and soil water salinity are the two primary factors affecting vegetation occurrence. Because of the brackish nature of Suisun Marsh water, careful management is necessary to prevent high soil salinities, especially in the western Marsh. Rollins (1981) found that circulation of water and multiple leach cycles below the pond bottom in the spring can reduce the salinity in the root zone and, coupled with specific flood durations, encourage the growth of alkali bulrush, fat hen and brass buttons, the most important foods according to early food habits studies based on gizzard analyses.

The determination and monitoring of water quality (primarily salinity) standards for the Suisun Marsh have been a focus of the technical and financial resources of several public agencies (Comprehensive Review 2001). Water salinity in the Marsh is subject to wide natural fluctuations as a result of daily tides, annual precipitation, and interannual cycles of drought and flood (Wells 1995). However, diversions of fresh water from the Sacramento and San Joaquin River systems for agricultural, industrial and urban uses have decreased delta outflow to 60% of its historic flows (Miller et al. 1975). Salinity of applied water in the Marsh has increased, primarily in the winter and spring of dry years, due to State Water Project and Central Valley Project storage and operations (Miller et al. 1975). Although water quality is improving because of remedial measures, such as salinity control facilities, to meet State Water Resources Control Board (SWRCB) salinity standards (SEW 2001). Residual salinity problems or new requirements to cease pumping in spring to protect Delta smelt (*Hypomesus transpacificus*) and winter run Chinook salmon (*Oncorhynchus tshawytscha*) smolts, may affect vegetation and food production and may in turn change food availability and consumption patterns of waterfowl using the managed areas of the Marsh. Authorities established current salinity standards for the Marsh based on the production of 1,000 lb/ac (1123 kg/ha) of alkali bulrush as the target objective. Alkali bulrush occurs naturally along the slough margins of the Marsh and requires a relatively intermediate salinity range. However, there are concerns that a salinity control program for such a large area should not revolve around the seed production of a single plant.

Statewide water transfers between agricultural and urban interests may soon play a role in shaping waterfowl distribution and habitat use within the Suisun-San Joaquin-Sacramento Valley region. As of December 31, 2002 the state of California was required by the federal government to reduce their use of Colorado River water by 800,000 acre feet (Quantification Settlement Agreement 2002). A key part of the agreement was a long term transfer of water from the largest rural water district in the state to the largest urban water district in the state. The districts were unable to reach an agreement and in February 2003 the urban water district began exercising options on several water contracts in the Sacramento Valley, which will idle over 60,000 acres of rice. Rice growers typically flood their fields in winter, in combination with other mechanical treatments, to encourage rice straw decomposition and waterfowl use, which has been shown to increase decomposition (Bird et al. 2000). Most of these water purchases are currently one year options, but urban water demands will only increase and longer term agreements involving larger acreages will impact wintering waterfowl use in the Marsh and Sacramento Valley.

Because of the many competing demands on Suisun Marsh water quality and quantity, new food habits data collected by modern methods are needed. Such data obtained in early autumn, when duck clubs and state wildlife areas are first flooded, will allow an assessment of the relationship between waterfowl foods consumed relative to their availability at feeding sites. Foods present in early fall result from marsh management procedures applied during the preceding year by wetland managers. As fall and winter progress, the most favored foods are gradually consumed and birds have fewer choices available to them. Analysis of foods eaten later in the season gives a different view of selected foods relative to those managed for by duck clubs and state areas. Such foods, being the "last left on the table," might not be the most desirable to target for increase through marsh management practices, even though they may be preferred by birds relative to other foods available at that time. If we can evaluate this relationship in Suisun and if the array of available foods varies across the Marsh, we will be able to assess the value to feeding waterfowl of certain key vegetation assemblages in various parts of the Marsh and relate these assemblages directly to marsh management practices. Since vegetation assemblages in the Marsh are a product of water management, including the salinity of applied water, this information will assist in assessing the effects of new salinity standards and issuing appropriate management recommendations.

We focused our efforts in this study on the food habits of green-winged teal, pintails and mallards within the Suisun Marsh. These three species are the most abundant wintering dabbling ducks in the Marsh and, being primarily granivorous, are the species most likely to consume foods that will reflect marsh management activities of state and private landowners. The primary focus of this investigation was to determine foods consumed by dabbling ducks relative to those available as the result of current management practices in Suisun Marsh (Miller et al. 1975, Rollins 1981). We also collected samples from pass-shot ducks and duck clubs to measure more extensive diet patterns and to compare nocturnal and diurnal diets.

STUDY AREA

Suisun Marsh is a brackish, estuarine wetland that consists of approximately 28,000 ha (69,000 ac) of managed and tidal wetlands, and about 10,000 ha (25,000 ac) of bays, sloughs, and waterways (Keeler-Wolf and Vaghti 2000). It is the largest single estuarine marsh in the United States and represents about 10% of the remaining marshlands in California (Rollins 1973). The Marsh is composed almost entirely of privately owned and managed duck clubs and SWAs. The vegetation is a combination of native and introduced annual and perennial upland and wetland plants, including pickleweed (*Salicornia virginica*), saltgrass (*Distichlis spicata*), various bulrush species (*Scirpus maritimus, S. californicus, S. acutus, S. americanus*), brass buttons, fathen (*Atriplex triangularis*), and many others. The Marsh is a heterogeneous environment with a variety of management types including tidal marsh, permanent ponds, and seasonally flooded units consisting of high and low marsh zones (Keeler-Wolf and Vaghti 2000).

METHODS

The study area consisted of wetlands on the Grizzly Island SWA complex and cooperating private duck clubs (Figure 1). We obtained data by: 1) shooting actively feeding birds (Miller 1987); 2) pass-shooting birds flying between night feeding areas and diurnal roosts (Miller 1987, Ely and Raveling 1989); and 3) collecting esophagi from hunter-shot ducks on duck clubs and SWAs (Delnicki and Reinecke 1986). In all instances we used only esophageal contents to avoid the bias associated with the use of gizzard contents. We also compared the contents of the gizzards and esophagi of a sample of actively feeding birds to assess the potential bias of using only gizzards. These data also permit comparison with analyses conducted by George et al. (1965) and Mall (1969).

Actively Feeding Ducks (feeding)

We collected actively feeding ducks in early September through October (1997 & 1998) to assess food habits soon after wetland managers initially flooded ponds and before the hunting season began. This allowed an analysis of the foods selected by ducks relative to the quantities and varieties of all foods present. We conducted a second round of collections in late November-early December to sample food selection during this period to account for foods that might mature later in the fall, such as fat hen (*Atriplex patula*) (Rollins 1981).

We collected green-winged teal, northern pintails, and mallards by shooting after observing them feed for at least 10 minutes (Swanson and Bartonek 1970, Swanson et al. 1974, Miller 1987). This observation period increased the likelihood that collected ducks would have food in their esophagi, but even feeding ducks can often be devoid of food (Miller 1987). We attempted collections from the eastern and western Marsh to increase the variety of sampled wetlands used by feeding ducks (Figure 2), which included ponds flooded at different times, depths and durations (Rollins 1981). We collected some birds on privately managed duck clubs after the hunting season began, but in general this was not possible after the start of the season and we confined the majority of our collections during hunting season to SWAs within the Marsh (Figure 2).

Ducks Returning to Roost (pass-shot)

The principal foraging period for wintering dabbling ducks occurs at night, especially by October (Miller 1985) after the onset of hunting season (Casazza 1995, Pirot 1983). However, collecting actively feeding ducks at night proved to be impractical. Additionally, tall stands of emergent moist soil vegetation in many Suisun Marsh ponds obscured visibility and precluded the collection of actively feeding ducks. Finally, the Marsh is large and access was not possible throughout, therefore, ducks could consume certain foods in large quantities, but we couldn't obtain verification if we limited our work to feeding ducks only. Thus, we attempted to shoot green-winged teal, pintails and mallards from flocks returning before daylight to heavily used diurnal sanctuaries on Joice Island SWA, Grizzly Island SWA, and the Garibaldi and Goodyear Slough Units of Grizzly Island SWA.

Foods from Hunter-shot Ducks (duck clubs)

We enlisted the cooperation of private duck clubs to collect the esophagi of hunter-shot ducks (Figure 3). These esophagi provided a large sample to supplement the smaller sample of pass-shot ducks and improved the extensive perspective on foods consumed at night within the Marsh. We provided collection kits with detailed collection instructions, pre-labeled jars filled with 70% ethanol, and scissors. We retrieved samples periodically throughout the season and stored them in a refrigerator until analyzed.

Processing Esophageal Contents

For all esophageal samples we removed food items immediately after collection in the field and placed the contents in 70% ethanol in plastic bags and stored them on ice in coolers. Upon return to the lab, we froze samples for subsequent analysis (Miller 1987). We relied on existing reference materials, seeds collected from the Marsh and published sources as described in Miller (1987) to identify seeds. Staff of the California Department of Food and Agriculture's Seed Laboratory in Sacramento identified several unknown seeds. We identified invertebrates using Pennak (1989), Merritt & Cummins (1997) and with the assistance of the Bohart Museum of Entomology staff at U. C. Davis. We washed esophageal contents through a 500 µm mesh sieve, sorted, identified and dried them to constant mass at 65° C. We report dry mass because of their direct application in nutritional and bioenergetic considerations (Reinecke & Owen 1980). We present data for each food item as percent occurrence and aggregate percent dry mass (Swanson et al. 1974, Miller 1987) for each food item:

$$\% \text{ occurrence} = \text{number of birds in which an item occurs} \div \text{total number of birds collected}$$

$$\text{aggregate } \% \text{ dry mass} = \Sigma\,(\text{mass of item in each bird} \div \text{mass of all items in each bird}) \div \text{total number of birds}$$

Processing Core Samples

We collected and processed five randomly located core samples from each site where actively feeding ducks were shot (Swanson and Bartonek 1970, Miller 1987). This provided the estimate of foods available at the feeding site against which we compare foods consumed. We processed core sample contents in the same way as we did the esophageal contents.

Statistical Analysis

We based statistical analyses on measures of aggregate percent dry mass. We transformed (arcsine-square root) all values prior to analysis for parametric tests; however, we used nonparametric tests when transformation did not normalize the data. In several cases, significant heterogeneity in variances prohibited the use of parametric Analysis of Variance (ANOVA) for comparisons among groups. We used nonparametric rank tests in these cases.

Duck club birds – We analyzed differences in diets among duck species and among seasons (months) using Kruskal-Wallis non-parametric ANOVA. We examined differences among years (1997, 1998) using Mann-Whitney U tests.

Pass-shot birds – We tested for differences between pass-shot and actively feeding birds (nocturnal vs. diurnal diet patterns) using paired t-tests.

Feeding birds – We analyzed differences in diet among duck species using parametric ANOVA or Kruskal-Wallis non-parametric ANOVA. We compared food use to food availability (preference) using three approaches. First, we examined diet preferences using program PREFER (Johnson 1980) and Friedman's Rank Test. Second, we calculated the difference between the proportion of each food item in the diet and available at the feeding site for each bird. We then used this difference (d) for each birds in paired t-tests and Wilcoxon Signed Ranks tests to test for differences in the proportion of each food item used relative to that available. Paired t-tests included values of zero (i.e., where a food item was not present in the diet or in the habitat) and so considered all birds. In contrast, the Wilcoxon Signed Ranks test omitted cases with zero values and so excluded birds that did not have a food item in the diet or in the habitat sample. Hence, the results of these tests may differ, with the Wilcoxon test indicating preference or avoidance of food items only for those birds which had made some choice. Finally, as an indication of preference for each food item, we calculated the Forage Ratio (Krebs 1988) as:

Proportion of item *i* in diet / Proportion of item *i* available at feeding site

Assessing Potential Gizzard Bias

We collected a sample of 35 gizzards from the actively feeding birds during the 1998-99 field season to test for the bias associated with earlier diet studies examining gizzard contents. We processed the gizzards and esophagi from each bird as noted above and we compared their contents using paired t-tests.

RESULTS

General Patterns of Food Use

A summary of ducks collected is provided in Table 1. The numbers in Table 1 are totals, with empty birds excluded from analyses. We found seeds from over 30 species of plants in the esophageal samples, but very little identifiable non-seed plant tissues (Tables 2-4). Seeds of 10 species accounted for over 90% of the aggregate percent dry mass for each species of duck (Figures 4-9). There were only two ducks that ate agricultural grains (rice and corn). We also recorded over 20 invertebrate taxa, predominantly in the pass-shot and feeding ducks. We itemized invertebrates only by percentage occurrence because they occurred in such small quantities. For each duck species (both years combined), only alkali bulrush and sea purslane (*Sesuvium verrucosum*) occurred in over 50% of all the collected esophagi (Tables 2-4). We found invertebrates in less than 1% of duck club birds; however, over 20% of pass-shot and actively feeding birds contained midge larvae (family *Chironomidae*), with several other taxa of invertebrates occurring at rates of 2-10% (Tables 2-4).

Duck Club Birds

Twelve private duck clubs in 1997-98 and twenty clubs in 1998-99 contributed 785 esophagi from their harvested birds during the two hunting seasons (Table 1, Figure 3). The three most frequently occurring items for green-winged teal (GW) were sea purslane (62%), pickleweed seeds (48%) and alkali bulrush (47%), although pickleweed seeds accounted for less than 8% aggregate dry mass. Sea purslane (32%), alkali bulrush (21%) and fat hen (19%) contributed the greatest aggregate percent dry mass for club GW.

Bulrush (60%), purslane (51%) and pickleweed (29%) occurrence exceeded all other food items in northern pintail (NP) esophagi. Pickleweed accounted for only 5% aggregate dry mass for club NP, well below several other items, including bulrush (40%), purslane (24%) and swamp timothy (9%).

For club mallards (MA) the highest percent occurrences were for bulrush (67%), purslane (49%), and watergrass (34%). These same foods contributed the highest aggregate percent dry mass: bulrush (35%), watergrass (19%) and purslane (17%) (Table 2).

We found very few invertebrates in club birds, with no species exceeding 0.2% occurrence, except three spiders that appeared in separate GW, raising their occurrence to 1.4%.

Pass-shot Birds

We found the most frequently occurring foods for pass-shot GW to be pickleweed (70%) and purslane (67%), with several other seeds occurring in almost half the birds. The seeds occurring in the highest aggregate percent dry mass for pass-shot GW were purslane (28%), fat hen (26%) and watergrass (17%).

For pass-shot NP the most frequently occurring items were bulrush (51%), purslane (49%) and watergrass (33%) and these items were also the highest in aggregate percent dry mass: watergrass (30%), bulrush (26%) and purslane (22%).

Bulrush (67%), purslane (61%) and watergrass (53%) also occurred most frequently in pass-shot MA. The top three food items by aggregate percent dry mass in pass-shot MA mirrored the order of that found in the NP: watergrass (41%), bulrush (23%) and purslane (20%).

Many more invertebrates were found in pass-shot birds than club birds. The highest percent occurence for all species was for midge larvae (average for all three species=23%), followed by seed shrimp for GW (24%), fly larvae for NP (5%) and water boatmen for MA (8%).

Feeding Birds

It proved to be very difficult to collect actively feeding green-winged teal and we were only able to collect five each field season. The most frequently occurring items for these ten GW were purslane (90%), rabbit's foot grass (60%) and brass buttons (50%). The bulk of the aggregate percent dry mass for feeding GW was accounted for by two items: purslane (79%) and brass buttons (17%).

The most commonly recorded items in feeding NP (n=39) were purslane (85%), bulrush (83%) and pickleweed (51%). Again, however, pickleweed was one of the lowest items in terms of aggregate percent dry mass (2%), with the top items for feeding NP being purslane (71%), watergrass (10%) and bulrush (9%).

The top food items for feeding MA (n=38) were bulrush (70% occurence, 34% aggregate dry mass), purslane (63% occurence, 27% aggregate dry mass) and watergrass (39% occurrence, 23% aggregate dry mass).

Midge larvae were the most frequently occurring invertebrate for all three species collected while actively feeding (GW-40%, NP-24%, MA-33%). The second most frequent invertebrate in the diets of feeding GW and NP were seed shrimp (GW-30%, NP-7%), while water boatmen (13%) and beetle larvae (13%) followed midge larvae for feeding MA.

Sources of Variation in Diet

Species Differences

Duck Club Birds (Figure 7; Table 5) – There were diet differences between the three duck species for 6 of the top 10 seeds by aggregate percent dry mass: fat hen, watergrass, smartweeds, pickleweed, bulrush and purslane (Table 5, all $P<0.05$). Green-winged teal consumed more purslane, pickleweed and fat hen than the other duck species (Figure 7). Mallards ate more watergrass and smartweeds than either GW or NP. Northern pintails and mallards consumed more bulrush than green-winged teal did.

Feeding Birds (Figure 9; Table 5) – For feeding birds there were species differences in consumption of brass buttons, rabbit's foot grass, pickleweed, bulrush and purslane (Table 5, all $P<0.05$). Mallards consumed less purslane than either GW or NP (Figure 9). Green-winged teal consumed more brass buttons than either MA or NP. Overall aggregate percent dry mass for pickleweed was low for all species (<1%), but NP consumed slightly more than MA. Mallards also consumed more watergrass than either NP or GW. Green-winged teal and NP consumed more rabbit's foot grass than MA, but the use of this food item was very low for all species.

Daily Differences

Feeding vs. Pass-shot birds (Figures 8 & 9; Table 6)- There were diet differences between birds collected while actively feeding and birds collected while returning from nocturnal feeding/roosting (pass-shot). Feeding GW and NP had higher aggregate percent dry masses of purslane than pass-shot GW and NP (Table 6). Feeding GW also had higher aggregate percent dry mass of brass buttons than pass-shot GW. Pass-shot NP consumed more watergrass than feeding NP and MA showed this same trend (Table 6). Pass-shot NP ate more bulrush than feeding NP, while MA showed the opposite pattern (Figures 8 & 9).

Seasonal Trends

We were unable to collect enough feeding and pass-shot birds to examine seasonal patterns, so only data from club birds are presented here (Figure 10; Table 5). All three species of ducks consumed bulrush in significant proportions throughout the season, however, GW decreased their use of bulrush in December and January. Ducks ate fat hen only sparingly during the first half of the season, GW used it heavily during December and January, while consumption of fat hen by mallards peaked in January. In contrast, ducks fed on swamp timothy most heavily in October and then quickly reduced use until January, at which time it did not appear at all in club duck diets. Watergrass was consumed by MA consistently throughout the season, with its peak occurring in January, while GW and NP used it only during the first half of the season. Sea purslane aggregate dry mass was highest for all three species during October, tapering off for NP and MA through the season, while remaining a significant portion of GW diets through January.

Yearly Differences

Although we did not sample specifically to detect differences in seed availability between years there are some consistent differences in availability at feeding sites for all three species (Figures 11-13). Brass buttons' seeds occurred in relatively low amounts at all three species' feeding sites during 1997 and was not detected in measurable quantities at any site in 1998. The proportion of available pickleweed seeds was higher at NP and MA sites for 1997. Bulrush occurred in greater amounts at feeding sites during the 1997 season for all three species, while purslane occurred in greater amounts for all three species during the 1998 season. Comparisons of food use also differed among years for several food items. Watergrass and brass buttons were found more often in waterfowl diets in 1997 than in 1998 (Table 5). Purslane was more abundant in the diets of all species in 1998 than in 1997.

Feeding Preferences (food use relative to food available)

Green-wings used diurnal feeding sites with the highest proportion of purslane seeds (73.6%, Table 7), followed by bulrush (16.0%). Green-winged teal had forage ratios > 1 for brass buttons, rabbit's foot grass, purslane and swamp timothy (Table 7). However, none of these preferences were statistically significant. Green-wings ate smartweed, watergrass and pickleweed in proportion to their availabilities, but avoided bulrush ($t=-2.57$, $p=0.03$, $Z=-1.84$, $p=0.07$) and fat hen ($t=-2.61$, $p=0.03$, $Z=-2.03$, $p=0.042$, Figures 14-15).

Northern pintails also used diurnal feeding sites with high proportions of purslane (55.1%), that also included bulrush (15.6%), watergrass (10.8%) and pickleweed (10.7%; Table 7). Pintails had positive forage ratios for purslane, fat hen and rabbit's foot grass, but their only significant preference was for purslane (Figure 14). They consumed watergrass and bulrush in relative proportion to their availabilities. Pintails exhibited a significant avoidance of brass buttons, smartweed, dock and pickleweed seeds (Table 7, Figures 14-15).

Mallards chose diurnal feeding sites with high proportions of purslane (35.6%), bulrush (25.7%), pickleweed (15.2%) and watergrass (11.8%). However, MA were neutral towards purslane and their only significant preference was for watergrass (Table 7, Figure 14). Mallards consumed bulrush, rabbit's foot grass, swamp timothy and dock relative to their availabilities and avoided pickleweed and fat hen (Figures 14-15)

Analyses of diet preferences using program PREFER and Friedman's Rank Test confirmed these patterns. Both tests gave comparable results, but the order of ranking of preferred food items differed somewhat. Friedman's Rank tests provided more consistent results with analyses based on each item separately and were more easily interpreted (see also Alldredge and Ratti 1986, 1992).

Due to the limited sample of GW (n=9), we could only include 9 food items in the analysis for that species. We excluded *Rumex* given that it was not present in appreciable amounts in either the diet or feeding site samples. GW did not exhibit preferences for any food item as determined with either Program PREFER or Friedman's Rank Test ($P>0.35$). In contrast, both NP and MA exhibited significant preferences ($P<0.05$, Program Prefer; $P<0.01$, Friedman's Rank Test; Table 8). The rank order of preferences differed somewhat when analyzed by Friedman's Test (Table 8) compared to the results of the paired t-tests, Wilcoxon Signed Ranks Tests and Forage ratios (Table 7). Both species exhibited significant selection against pickleweed.

Comparison of Gizzard vs. Esophageal Contents

We compared the aggregate percent dry mass of the top ten seeds from the gizzards and esophagi of a sample of 35 feeding birds from 1998 (Figure 16). The only seed that was significantly overrepresented in the gizzard was alkali bulrush ($t = 4.82$, $P < 0.0001$). There were no relationships between the dry mass of any food item in the esophagus and its mass in the gizzard.

DISCUSSION

Comparisons to Previous Diet Study

Gizzard Versus Esophageal Contents

Based on gizzard contents, George et al. (1965) concluded that alkali bulrush was the most important food item for ducks wintering in the Suisun Marsh. Using esophageal contents, we found that alkali bulrush remained a large part of waterfowl diets within the Marsh (Tables 2-4). However, we compared a sample of esophageal contents to their respective gizzard contents and found that alkali bulrush was the only food item consistently and significantly overrepresented in the gizzard. Had we used gizzards instead of esophagi our results would have been biased towards alkali bulrush as predicted by studies subsequent to George et al. (Swanson & Bartonek 1970).

Preference Analyses

Mall's (1969) calculations of waterfowl food preference were based on ground coverage of each food plant as determined from aerial photographs by George et al. (1965). However, the ground coverage of plants viewed from above does not directly correlate to its food value to waterfowl. Further, many of these food plants may not have been available to wintering waterfowl because not all areas within the Marsh are flooded in winter. Mall's calculations also neglected important considerations with regard to plant growth patterns, seasonal availability, and whether each duck species consumed primarily seeds or non-seed plant tissues. Our preference analyses were based on samples taken at each feeding site from actively feeding birds, thus reducing possible errors that may have resulted from mismatched sampling scales (aerial photographs and hunter-shot birds without feeding location data), changes in seasonal availability of seeds due to depletion and decomposition, and confusion arising from neglecting to consider the general food preference of each duck species.

Waterfowl Food Preferences

Alkali bulrush *(Scirpus maritimus)*

Our preference analyses showed that bulrush was avoided by green-winged teal and neither pintails nor mallards showed a preference for it, which suggests they are consuming it only in proportion to its availability. Earlier studies tracked a positive correlation between management promoting alkali bulrush and its quantity in pintail diets (1947-8%, 1949-21.3%, 1957-26%, 1960-37%, George et al. 1965). Other studies have shown that bulrush seeds pass mostly undigested through the digestive tracts of waterfowl and that birds may be substituting these hard seeds for grit (Pederson and Pederson 1983, Beer and Tidyman 1942, Mueller and van der Valk 2002). The relative value of bulrush as grit or food likely depends on the relative composition and range of sizes and hardnesses of the items eaten during a particular feeding.

Alkali bulrush occurs naturally along the sloughs within the greater San Francisco/San Pablo/Suisun Bay Estuary, propagating primarily via rhizomatous growth, but also producing abundant seed in wet years. Alkali bulrush is most productive in tidal marshes where it experiences large seasonal salinity changes (Pearcy et al. 1982). Salinity standards for Suisun Marsh, in place since the 1970's, currently focus on providing low spring soil salinities for bulrush seed production in managed wetlands. Management plans for alkali bulrush in diked wetlands are well suited to the Suisun environment because of its importance in the diet of several waterfowl species, its tolerance of summer drying, which also discourages mosquito production, and because the watering schedule also promotes the growth of fat hen and brass buttons as sub-dominant plants in a community with alkali bulrush (Rollins 1981). The most recent vegetation survey conducted by CDFG in 1999 showed only 2505 acres of *Scirpus maritimus* dominated area within the Marsh, but bulrush seeds can often be retained in soil seed banks many years after the loss of standing vegetation (this study).

Sea purslane *(Sesuvium verrucosum)*

We found that feeding pintails preferred sea purslane and, along with green-winged teal, selected feeding sites with high proportions of available sea purslane, while mallards consumed it in proportion to its availability. Data from all three types of collections show purslane to rival bulrush in terms of overall importance in the diet, especially for green-winged teal, all early season birds, and dominating in diurnally feeding teal and pintail diets. In contrast, George et al. (1965) identified only trace amounts of sea purslane in the diets of teal, pintails and mallards in the Marsh during the 1960-61 fall-winter period. Data from 1960 show purslane occurring in 15.3% of early season collected pintails, absent for winter and spring pintails, as a trace amount in mallards only in spring, and as completely absent from the diets of green-winged teal.

Research from the South Carolina coast has shown that purslane grows best in organic soils, the seeds are relatively high in crude fat and protein and are preferred by blue-winged teal, green-winged teal and northern pintail (Swiderek et al. 1988). However, management of sea purslane is not well understood. Anecdotal evidence from Suisun Marsh suggests that purslane grows in the lowest pond bottom elevations under the most saline soil conditions. Landowners in the Marsh report that they haven’t actively managed for sea purslane, but began to notice large expanses several years ago. Sea purslane grows prostrate and produces many small, round, black seeds about 0.5 mm in diameter that are shed in mid to late September. This timing corresponds with the return of ducks to the Marsh in fall and pre-season flood up of ponds.

Brass buttons *(Cotula coronopifolia)*

We found brass buttons to be a small contributor to waterfowl diets-eaten by green-wings and pintails, but not preferred, and nearly avoided by mallards. Brass buttons was previously cited as the third most important food plant for dabbling ducks wintering in the Marsh (Mall 1969). However, in the 1960-61 season the consumption of brass buttons was heavily weighted towards the months of August and September, with only green-winged teal using it in measurable amounts during December and January (Figure 17). Further, most of the gizzards collected during this earlier study were from hunters using Grizzly Island Wildlife Area, where there was a noted abundance of brass buttons that were flooded prior to the hunting season to provide food for early arriving ducks. Another study identified nocturnal locations of radio-marked pintails as areas with high densities of brass buttons (Casazza 1995) and inferred that they were feeding at those sites. However, an extended drought preceded and encompassed that study (1987-1992) when 5 out of 6 water years were classified as "critical" by the Department of Water Resources.

Brass buttons' germination, flowering and seed production are highly sensitive to the timing and duration of water levels, preferring short submergence times (2-4 months). Both of our study seasons were classified as "wet", including a major flood event in January 1998, which may have limited the opportunities for brass buttons production. Brass buttons is an introduced species that is a prolific producer of very small seeds and grows in lower, more saline and disturbed areas of the Marsh (Rollins 1981).

Watergrass *(Echinochloa crusgalli)*

We found that watergrass was the only food item for which mallards demonstrated a strong preference, while green-wings and pintails ate it in proportion to its availability. Watergrass was present in significant amounts for mallards throughout the season, day and night, and for nocturnally feeding pintails and green-winged teal. George et al. (1965) reported that watergrass was present in mallards, pintails and green-winged teal, but never exceeded 6% by percentage volume. Compared to George, our results show that watergrass occurred in much greater quantities in 1997-99 and was especially important for mallards late in the season.

Watergrass is a cultivar planted in many waterfowl areas in the U.S. to provide cover and large, abundant seeds. Rollins (1981), in his guide to waterfowl management for the Marsh, provided a management schedule for watergrass, but stated that it is "...expensive to grow and receives intensive, short-lived use by waterfowl." Of all the waterfowl food plants in the Marsh it requires the lowest soil salinities (5 ppt), the freshest applied water, and several summer irrigations (Rollins 1981). Although strongly preferred by mallards throughout the season, it did not occur historically in the marsh and may not be a realistic long term management goal for a managed brackish marsh (IEP 2001).

Fat hen *(Atriplex triangularis)*

Pintails ate fat hen in proportion to its availability, while green-wings and mallards avoided it. We also found that fat hen occurred in greater quantities in ducks contributed by duck clubs and in pass-shot birds (especially green-winged teal), which suggests this food item is consumed in largest quantities nocturnally. Nocturnal use of fat hen may have been a factor in the earlier studies (George et al. 1965, Mall 1969) that determined fat hen to be a major component of waterfowl diets because all of their gizzard samples were contributed by hunters who traditionally shoot their birds in the early morning.

Fat hen is a brackish upper marsh native that produces abundant seeds, is adapted to disturbed soils, and occurs interspersed with other brackish plant species (George et al. 1965, Rollins 1981).

Factors Underlying Variation in Waterfowl Diets and Preferences

Resource selection by animals occurs at several levels; ducks in the Suisun Marsh first select ponds in which to roost and feed, then they select a feeding site, and, finally, they choose which items to eat based on their availabilities and profitabilities (Johnson 1980). Factors playing a role in selection at the level of the feeding site include neck and bill morphology, water depth and quality, food availability, and predation pressure. The overriding factor determining food abundance and availability is yearly climatic variation.

Yearly Variation

Our feeding site data show consistent differences between years for the availability of several food items, including brass buttons, watergrass, bulrush and sea purslane. These differences in seed availability are also consistent across all three duck species suggesting that annual climatic variation, primarily in the form of precipitation and temperature, played an important role in seed production within the diked, managed wetlands of the Suisun Marsh.
Annual climatic variation can often be the predominate factor influencing wintering waterfowl diet and survival (Combs & Fredrickson 1996, Fleskes et al. 2002). In most other areas of the country, wintering waterfowl are directly affected by snow and temperature extremes, but for granivorous ducks wintering in the mild winters of California's mediterranean climate it is the previous year's precipitation that most directly affects their survival. Winter precipitation controls the salinity of water available to Suisun Marsh managers for the remainder of the calendar year and water salinity is the primary factor in

encouraging the growth and seed production of Marsh plants (Rollins 1973 & 1981, Michny 1979, Casazza 1995).

Seasonal Variation

Our data also show patterns in the seasonal use of food plants: use of bulrush throughout the season by all three species, early use of swamp timothy by all three species, heavier use of fat hen by green-winged teal in late fall, and consistent consumption of watergrass by mallards throughout the season, while teal and pintails only ate it in September and October (Figure 10). The earlier diet study showed a similar seasonal pattern for swamp timothy and fat hen, but watergrass appeared in consistently low amounts for all three species throughout the season (Figure 17). These patterns are a combination of the different diet preferences of duck species, plant life cycles, the persistence of different seeds in the soil bank, and flooding. Of these factors, the only one under the control of managers is the the timing and depth of flooding, which can have a great effect on use by feeding waterfowl. Previous studies have identified the importance of the Marsh as critical early-season habitat, especially during droughts, for birds that arrive as early as mid-August when there are only limited wetland and flooded agricultural habitats available in the Central Valley (George et al. 1965, Miller et al. 1975, Casazza 1995).

Daily Variation

We found significant differences in feeding choices between pass-shot birds (reflecting nocturnal feeding) and actively feeding birds collected diurnally (Table 6). These differences reflect the birds' general preference for open habitats during the day and more closed habitats at night. For example, mallards and pintails consumed more watergrass (tall growth-reduced visibility) at night and pintails and green-winged teal consumed large amounts of sea purslane (prostrate growth-good visibility) during the day. We attempted some collections at night, but abandoned those efforts because we were unable, using available night vision technology, to identify duck species and safely and humanely collect birds. Dabbling ducks differ in their food selection on a daily cycle (Miller 1987, Euliss 1984). Pintails in the San Joaquin Valley spent most of their feeding time in dense vegetative cover at night consuming watergrass (Euliss and Harris 1987). Studies within Suisun Marsh show strong differences between nocturnal and diurnal habitat use (Casazza 1995) and have documented intense waterfowl feeding activity at night (Pirot 1983).

Species Differences

Our data indicate a trend from larger ducks consuming larger seeds (mallards and watergrass) to smaller ducks consuming smaller seeds (green-winged teal and sea purslane) (Table 9). This is consistent with previous studies that found the body size of dabbling ducks to be positively related to their lamellar spacing, which, in turn, allows them to efficiently exploit prey of different sizes (Batzer et al. 1993, Nudds and Bowlby 1984). Additionally, ducks may shift their preferences seasonally to take advantage of the most profitable food items given the constraints of lamellar spacing, water depth, food availability and competition from other species (Guillemain et al. 2002).

Research Needs

Management of Sea Purslane

Sea purslane has become a major food item in the diets of dabbling ducks wintering in the Suisun Marsh. Unfortunately, there is little known about the ecology of purslane in the Marsh. Swiderek (1982) noted that purslane was most productive on organic soils, grew well under drought conditions in managed brackish impoundments, and produced seeds high in crude fat and protein. Future studies should examine the distribution of sea purslane in Suisun, develop management techniques to promote and control it (disturbance, elevation, length of submergence, soil salinity), learn about its potential effects on existing plant communities in the Marsh, and evaluate its benefits to other wildlife species, including its value as invertebrate habitat.

Late Winter/Spring Waterfowl Diets

Our food habits collections ended in December because our focus was on granivorous duck species and on the seeds from plants, grown in the previous season, most important in their diets. Most dabbling ducks, especially females, switch from diets dominated by plants to invertebrate diets in late winter and spring to prepare for the nutritional demands of nesting (Miller 1987, Euliss 1984). The upland fields of the Grizzly Island SWA are productive mallard nesting habitat (McLandress et al. 1996). Batzer and Resh (1992) and deSzalay and Resh (1997) studied the relationship between habitat management techniques and invertebrate populations in the Suisun Marsh, and Batzer et al. (1993) examined consumption of invertebrates in the Marsh by mallards and green-winged teal. However, the vegetation manipulation studies included saltgrass, not typically flooded for waterfowl, and the diet study was limited by very small sample sizes. Future research in this area should include habitats typically flooded during late winter and spring (post hunting season), and the effects of water quality on invertebrate production. Since waterfowl broods consume a diet of almost exclusively invertebrates during their first two weeks of life (see review in Sedinger 1992), studies need to examine the relationship between habitat management and waterfowl brood survival.

Red Water

The unnatural flooding and draining of previously tidal brackish marsh soils can lead to low pH “cat clay” conditions and the production of an iron flocculent that creates “red water” (Neely 1958). Research has shown that dabbling ducks regularly feed and roost in “red water” ponds, both in the field and under experimental laboratory conditions (USGS 1999, this study). However, the flooding regime practiced by most clubs within the Marsh (flooded October through January, then dry) may lead to increasingly acidic soils over the long term and a reduction in vigor and seed production of waterfowl food plants (Crapuchettes 1999). Long term studies are needed to examine the consequences of moist soil management on soil acidification, including its effects on vegetation and seed production. It is critical that seed production remain high to continue to support large wintering waterfowl populations.

Importance of Sanctuary and Disturbance

The importance of sanctuary to waterfowl in the Suisun Marsh has long been recognized (Moffitt 1938, Pirot 1983). Compared to the Delta and Valley regions Suisun Marsh has a low sanctuary to hunted area ratio. The distribution of sanctuary areas throughout the Marsh could be critical to holding birds through the winter and preventing concentrated food depletion and disease outbreaks (Pirot 1983, Casazza 1988). Research has shown that low ratios of sanctuary to hunted area may affect winter survival of pintails (Fleskes 2002). Suisun Marsh is subject to many sources of disturbance and effects on waterfowl behavior have been observed (Pirot 1983). Observing and collecting actively feeding waterfowl, as we did in this study, requires an investment of large numbers of hours in scouting and stealth. We experienced disturbance (hunting, vehicle traffic, fishing, mosquito abatement activities, overflights from Travis AFB) on nearly every collection attempt, often resulting in the abandonment of the collection effort. Waterfowl disturbed from their normal activity patterns may exhibit lower survival rates, especially during inclement weather, at critical migratory stopover sites or when food supplies have been depleted (Belanger and Bedard 1990, Wolder 1993). Studies are needed to document the types of disturbance, measure their effects on feeding and roosting activity, investigate the consequences of the interspersion of sanctuary with hunted areas, and plan for sanctuary design and placement.

The Role of Suisun Marsh in the CVHJV

The Suisun Marsh is part of the Central Valley Habitat Joint Venture (CVHJV), which is the regional group implementing the North American Waterfowl Management Plan. The CVHJV implementation plan (1990) establishes population objectives for waterfowl species and the habitat goals necessary to support those population levels based on a bioenergetic model. The bioenergetic model hinges on estimates of food availability, which were initially taken from studies conducted in the midwest, but are now being updated by studies conducted in the Sacramento and San Joaquin Valleys (Naylor et al. 2002). Estimates of food density, distribution, and depletion would support the bioenergetic foundations of the CVHJV and help determine waterfowl distribution relative to available water quality in the Suisun Marsh.

Tidal Marsh

Prior to the conversion of most of its natural, tidally influenced land to diked, managed ponds, Suisun Marsh supported abundant waterfowl populations (Stoner 1937, Moffitt 1938, Arnold 1996). Most of the food plants used by waterfowl occur naturally in tidal areas of the Marsh, albeit in lower densities within more diverse vegetation assemblages, and many of these species can also be grown in well designed, constructed and managed diked wetlands (IEP 2001). There is interest in returning some areas of the Marsh to tidal influence (SFB Ecosystem Goals 1999) to support a greater diversity of native flora and fauna that includes waterfowl. Tidal areas within the Marsh have been reduced to less than 6,000 acres and we did not collect feeding ducks in these areas because most are in close proximity to residential areas and support heavy public use. However, future research in tidal areas within the Marsh should include waterfowl diet investigations and how to manage these areas given the complexities of the infrastructure in the Marsh.

MANAGEMENT IMPLICATIONS

Our data indicate there have been some shifts in waterfowl food preferences since the 1960's due to marsh management goals, the introduction and propagation of new plant species, and interannual climatic variation.

- Alkali bulrush remains an important part of waterfowl diets in Suisun Marsh. Since the documentation of its role in waterfowl diets and the publication of a guide to its management in the early 1970's, bulrush has been the primary objective of Marsh managers and an index for water salinity monitors. Bulrush is a native species well adapted to the natural salinity range of the Marsh. However, bulrush does not provide for all duck species using the marsh and managing exclusively for bulrush can fill in pond bottoms, reducing the diversity of wetland vegetation and making these areas less desirable for waterfowl seeking open feeding and roosting areas.
- The single largest change in the diets of dabbling ducks wintering in the Suisun Marsh is the appearance and prevalence of sea purslane. The management methods for purslane remain unexamined. However, anecdotal evidence shows that it grows in the lowest, most saline sections of pond bottoms, suggesting that management plans for monocultures of sea purslane would preclude a diversity of plants valuable to waterfowl and other wildlife.
- Compared to earlier studies, brass buttons occurred in much lower amounts in the diets of ducks during our study. This was probably due to a combination of the earlier study's restricted sampling area and the wet conditions during our study which may have reduced the growth and seed production of brass buttons. Brass buttons' pattern of early season

availability, small seed size, and use by green-winged teal throughout the season is very similar to the patterns of sea purslane as revealed by our data.

- Our data show that watergrass is the preferred food item for mallards wintering in the Marsh and mallards increasingly rely on it as the season progresses. Watergrass, relative to management for other vegetation within the Marsh, requires fresher water and frequent irrigations, which may not be possible in some areas of the marsh and possible in other areas only in normal to above average rainfall years. Watergrass acreage in the marsh has increased since the 1960's due to salinity control measures and more intensive wetland management. Continued installation and improvements in the ability to control water in managed areas of the Marsh may help make watergrass a more realistic goal for managers.
- Most importantly, our data show that ducks feed on a range of food plants that require a range of salinities (Figure 18). To provide food for a diversity of duck species and be prepared for variability in interannual precipitation efforts should focus on maintaining a diversity of vegetation, flooding schedules and water depths. An effective management strategy begins with the ability to move and maintain pond water quickly, which requires suitable pond elevations and infrastructure. Well designed and constructed ponds allow managers the flexibility in flooding to leach soil salts, irrigate young plants, and inundate waterfowl food plants at varying depths and times during the season to attract feeding ducks.

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Table 1. Numbers of ducks collected from the Suisun Marsh September-January 1997-98 and 1998-99.

1997-98 Collections	Actively feeding	Returning from night feeding (pass-shot)	Shot at duck clubs	Totals
Green-winged teal	5	16	64	85
Northern pintail	24	21	51	96
Mallard	27	25	115	167
Totals	56	62	230	348
1998-99 Collections				
Green-winged teal	5	17	134	156
Northern pintail	17	17	92	126
Mallard	17	32	106	155
Totals	39	66	332	437

Table 2. Esophageal contents of green-winged teal (GW), northern pintails (NP) and mallards (MA) shot at duck clubs in the Suisun Marsh October-January 1997-98 and 1998-99 (both years combined).

	% Occurrence				Aggregate % Dry Mass			
Seeds	GW	NP	MA	Total	GW	NP	MA	Total
Asters (*Aster* spp.)	15.97	6.48	7.29	9.91	1.40	1.18	0.56	0.99
Fat-hen (*Atriplex triangularis*)	43.75	19.44	27.08	30.63	19.03	2.42	5.04	8.89
Fivehook bassia (*Bassia hyssopifolia*)	0.69	0.00	0.00	0.23	0.02	0.00	0.00	0.01
Lambs quarters (*Chenopodium album*)	8.33	0.93	7.29	6.08	1.53	0.01	0.71	0.80
Brass buttons (*Cotula coronopifolia*)	21.53	8.33	13.54	14.86	1.76	0.42	0.40	0.84
Swamp timothy (*Crypsis schoenoides*)	20.83	24.07	21.35	21.85	3.97	8.77	7.24	6.57
Sedges (*Cyperus* spp.)	0.00	0.00	0.52	0.23	0.00	0.00	0.01	0.00
Salt grass (*Distichlis spicata*)	2.08	0.00	1.56	1.35	0.06	0.00	0.00	0.02
Watergrass (*Echinochloa crusgalli*)	18.75	20.37	34.38	25.90	2.22	8.36	18.76	10.86
Sunflower (*Helianthus* spp.)	0.00	0.00	2.08	0.90	0.00	0.00	0.38	0.17
Wild lettuce (*Lactuca* spp.)	1.39	0.00	0.00	0.45	0.00	0.00	0.00	0.00
Bird's foot trefoil (*Lotus corniculatus*)	0.69	0.93	1.04	0.90	0.01	0.00	0.00	0.00
Italian ryegrass (*Lolium multiflorum*)	0.00	0.93	1.04	0.68	0.00	0.06	0.44	0.20
Rice (*Oryza sativa*)	0.00	0.93	0.52	0.45	0.00	0.92	0.53	0.46
Bristly ox-tongue (*Picris echioides*)	2.78	0.93	2.08	2.03	0.00	0.00	0.00	0.00
Smartweed (*Polygonum* spp.)	6.25	10.19	17.71	12.16	0.42	2.85	3.92	2.53
Rabbit's foot grass (*Polypogon monspeliensis*)	32.64	11.11	21.35	22.52	7.63	0.81	2.34	3.66
Pondweed (*Potamogeton* spp.)	1.39	2.78	7.29	4.28	0.74	0.46	3.04	1.66
Dock (*Rumex* spp.)	13.89	10.38	14.06	12.78	0.08	1.02	0.40	0.50
Pickleweed (*Salicornia virginica*) seeds	47.92	28.70	25.52	33.56	7.71	5.19	2.66	4.91
Pickleweed (*Salicornia virginica*) stems	0.69	0.00	0.00	0.23	0.01	0.00	0.00	0.00
Bulrush (*Scirpus* spp.)	47.22	60.19	67.19	59.01	21.02	39.77	35.32	31.82
Sea purslane (*Sesuvium verrucosum*)	61.81	50.93	48.96	53.60	31.72	24.09	16.99	23.50
Black nightshade (*Solanum nigrum*)	0.69	1.85	1.04	1.13	0.55	0.50	0.01	0.31
Sow thistle (*Sonchus oleraceus*)	0.69	1.85	1.04	1.13	0.00	0.00	0.00	0.00
Salt marsh sand spurry (*Spergularia marina*)	0.69	0.00	0.00	0.23	0.00	0.00	0.00	0.00
Chickweed (*Stellaria media*)	0.69	0.93	0.00	0.45	0.01	0.00	0.00	0.00
Wheat (*Triticum aestivum*)	0.00	0.00	0.52	0.23	0.00	0.00	0.42	0.18
Cattail (*Typha* spp.)	2.08	0.00	0.00	0.68	0.00	0.00	0.00	0.00
Horned pondweed (*Zannichellia palustris*)	0.00	0.00	1.04	0.45	0.00	0.00	0.01	0.00
Corn (*Zea mays*)	0.00	2.78	0.52	0.90	0.00	2.22	0.53	0.78
Other seeds	0.05	0.03	0.05	0.04	0.01	0.12	0.03	0.05
Misc. vegetation	31.94	31.48	34.38	32.88	* no weights taken			
Grit	38.89	37.04	40.10	38.96	* no grit weights taken			

continued…

Table 2. Esophageal contents of green-winged teal (GW), northern pintails (NP) and mallards (MA) shot at duck clubs in the Suisun Marsh October-January 1997-98 and 1998-99 (both years combined).

Table 2. Continued.

Invertebrates	% Occurrence				Aggregate % Dry Mass
	GW	NP	MA	Total	* invertebrate biomass too low for weights
Spiders (C. Arachnida)	1.39	0.00	0.01	0.01	
Beetles (F. Carabidae)	0.01	0.00	0.01	0.01	
Midge larvae (F. Chironomidae)	0.17	0.07	0.13	0.13	
Leaf beetles (F. Chrysomelidae)	0.00	0.00	0.00	0.00	
Snout beetles (F. Curculionidae)	0.01	0.00	0.01	0.00	
Water boatmen (F. Corixidae)	0.01	0.00	0.03	0.02	
Plant hoppers (F. Dictyopharidae)	0.01	0.00	0.00	0.00	
Diving beetles (F. Dytiscidae)	0.02	0.00	0.02	0.01	
Brine flies (F. Ephydridae)	0.10	0.02	0.04	0.06	
Ants (F. Formicidae)	0.03	0.02	0.02	0.02	
Minute moss beetles (F. Hydraenidae)	0.01	0.00	0.00	0.00	
Water scavenger beetles (F. Hydrophilidae)	0.01	0.00	0.00	0.00	
Assassin bugs (F. Reduviidae)	0.00	0.00	0.00	0.00	
Bird lice (F. Menoponidae)	0.01	0.01	0.00	0.00	
Thrips (F. Phlaeothripidae)	0.01	0.00	0.01	0.00	
Rove beetles (F. Staphylinidae)	0.01	0.00	0.00	0.00	
Hover fly larvae (F. Syrphidae)	0.00	0.00	0.01	0.00	
Horse flies (F. Tabanidae)	0.00	0.00	0.01	0.00	
Crayfish (O. Amphipoda)	0.00	0.02	0.01	0.01	
Water fleas (O. Cladocera)	0.00	0.00	0.00	0.00	
Water flea eggs (O. Cladocera)	0.07	0.02	0.03	0.04	
Other beetle larvae (O. Coleoptera)	0.02	0.00	0.02	0.02	
Fly larvae (O. Diptera)	0.00	0.00	0.00	0.00	
Snails (O. Gastropoda)	0.09	0.01	0.02	0.04	
True bugs (O. Hemiptera)	0.00	0.00	0.00	0.00	
Termite (O. Isoptera)	0.00	0.00	0.00	0.00	
Seed shrimp (O. Ostracoda)	0.11	0.03	0.03	0.06	
False scorpion (O. Pseudoscorpiones)	0.01	0.00	0.00	0.00	
Other invertebrates	0.01	0.00	0.01	0.00	
Misc. fragments	0.23	0.09	0.17	0.17	

Table 3. Esophageal contents of green-winged teal (GW), northern pintails (NP) and mallards (MA) collected upon return to day roosts from night feeding in the Suisun Marsh October-December 1997 and 1998 (both years combined).

Seeds	% Occurrence				Aggregate % Dry Mass			
	GW	NP	MA	Total	GW	NP	MA	Total
Asters (*Aster* spp.)	27.27	8.11	7.84	13.22	4.28	0.01	0.00	1.22
Fat-hen (*Atriplex triangularis*)	48.48	37.84	23.53	34.71	25.75	5.78	1.96	9.88
Fivehook bassia (*Bassia hyssopifolia*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lambs quarters (*Chenopodium album*)	0.00	0.00	1.96	0.83	0.00	0.00	0.00	0.00
Brass buttons (*Cotula coronopifolia*)	48.48	10.81	13.73	22.31	2.58	0.94	0.02	1.02
Swamp timothy (*Crypsis schoenoides*)	24.24	13.51	13.73	16.53	0.11	6.63	5.59	4.35
Sedges (*Cyperus* spp.)	3.03	0.00	0.00	0.83	0.00	0.00	0.00	0.00
Salt grass (*Distichlis spicata*)	3.03	0.00	0.00	0.83	0.00	0.00	0.00	0.00
Watergrass (*Echinochloa crusgalli*)	33.33	43.24	52.94	44.63	17.05	30.06	40.84	30.82
Sunflower (*Helianthus* spp.)	0.00	0.00	1.96	0.83	0.00	0.00	0.51	0.21
Wild lettuce (*Lactuca* spp.)	6.06	0.00	0.00	1.65	0.02	0.00	0.00	0.00
Bird's foot trefoil (*Lotus corniculatus*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Italian ryegrass (*Lolium multiflorum*)	3.03	2.70	7.84	4.96	0.96	0.42	3.87	2.00
Rice (*Oryza sativa*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bristly ox-tongue (*Picris echioides*)	6.06	2.70	5.88	4.96	0.01	0.91	0.00	0.28
Smartweed (*Polygonum* spp.)	15.15	18.92	29.41	22.31	1.60	0.24	3.45	1.96
Rabbit's foot grass (*Polypogon monspeliensis*)	48.48	24.32	21.57	29.75	2.60	2.35	0.15	1.51
Pondweed (*Potamogeton* spp.)	0.00	2.70	1.96	1.65	0.00	0.01	0.00	0.00
Dock (*Rumex* spp.)	9.09	24.32	17.65	17.36	0.16	2.09	0.06	0.70
Pickleweed (*Salicornia virginica*) seeds	69.70	13.51	25.49	33.88	11.74	2.88	0.19	4.29
Pickleweed (*Salicornia virginica*) stems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulrush (*Scirpus* spp.)	45.45	51.35	66.67	56.20	5.52	25.93	22.59	18.74
Sea purslane (*Sesuvium verrucosum*)	66.67	48.65	60.78	58.68	27.63	21.73	20.04	22.71
Black nightshade (*Solanum nigrum*)	0.00	0.00	3.92	1.65	0.00	0.00	0.00	0.00
Sow thistle (*Sonchus oleraceus*)	3.03	2.70	3.92	3.31	0.00	0.00	0.00	0.00
Salt marsh sand spurry (*Spergularia marina*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chickweed (*Stellaria media*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat (*Triticum aestivum*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cattail (*Typha* spp.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Horned pondweed (*Zannichellia palustris*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn (*Zea mays*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other seeds	3.03	2.70	7.84	4.96	0.01	0.00	0.72	0.30
Misc. vegetation	36.36	24.32	25.49	28.10	* no weights taken			
Grit	27.27	35.14	37.25	33.88	* no grit weights taken			

continued…

Table 3. Esophageal contents of green-winged teal (GW), northern pintails (NP) and mallards (MA) collected upon return to day roosts from night feeding in the Suisun Marsh October-December 1997 and 1998 (both years combined).

Table 3. Continued.

Invertebrates	% Occurrence				Aggregate % Dry Mass			
	GW	NP	MA	Total	GW	NP	MA	Total
Spiders (C. Arachnida)	0.00	2.70	0.00	0.83	* invertebrate biomass too low for weights			
Beetles (F. Carabidae)	0.00	0.00	0.00	0.00				
Midge larvae (F. Chironomidae)	42.42	16.22	15.69	23.14				
Leaf beetles (F. Chrysomelidae)	0.00	0.00	0.00	0.00				
Snout beetles (F. Curculionidae)	0.00	0.00	0.00	0.00				
Water boatmen (F. Corixidae)	12.12	2.70	7.84	7.44				
Plant hoppers (F. Dictyopharidae)	0.00	0.00	0.00	0.00				
Diving beetles (F. Dytiscidae)	15.15	0.00	1.96	4.96				
Brine flies (F. Ephydridae)	12.12	0.00	5.88	5.79				
Ants (F. Formicidae)	0.00	0.00	0.00	0.00				
Minute moss beetles (F. Hydraenidae)	0.00	2.70	0.00	0.83				
Water scavenger beetles (F. Hydrophilidae)	3.03	2.70	0.00	1.65				
Assassin bugs (F. Reduviidae)	0.00	0.00	0.00	0.00				
Bird lice (F. Menoponidae)	6.06	0.00	0.00	1.65				
Thrips (F. Phlaeothripidae)	3.03	0.00	0.00	0.83				
Rove beetles (F. Staphylinidae)	0.00	0.00	0.00	0.00				
Hover fly larvae (F. Syrphidae)	3.03	5.41	0.00	2.48				
Horse flies (F. Tabanidae)	0.00	0.00	0.00	0.00				
Crayfish (O. Amphipoda)	0.00	0.00	0.00	0.00				
Water fleas (O. Cladocera)	0.00	0.00	0.00	0.00				
Water flea eggs (O. Cladocera)	6.06	0.00	1.96	2.48				
Other beetle larvae (O. Coleoptera)	0.00	0.00	0.00	0.00				
Fly larvae (O. Diptera)	0.00	0.00	0.00	0.00				
Snails (O. Gastropoda)	9.09	0.00	1.96	3.31				
True bugs (O. Hemiptera)	0.00	0.00	0.00	0.00				
Termite (O. Isoptera)	0.00	0.00	0.00	0.00				
Seed shrimp (O. Ostracoda)	24.24	0.00	0.00	6.61				
False scorpion (O. Pseudoscorpiones)	0.00	0.00	0.00	0.00				
Other invertebrates	0.00	0.00	0.00	0.00				
Misc. fragments	27.27	10.81	11.76	15.70				

Table 4. Esophageal contents of green-winged teal (GW), northern pintails (NP) and mallards (MA) collected while actively feeding in the Suisun Marsh October-December 1997-98, 1998-99 (both years combined).

	% Occurrence				Aggregate % Dry Mass			
Seeds	GW	NP	MA	Total	GW	NP	MA	Total
Asters (*Aster* spp.)	10.00	7.32	6.52	7.22	0.01	0.00	0.04	0.02
Fat-hen (*Atriplex triangularis*)	20.00	29.27	10.87	19.59	0.02	2.45	0.27	1.18
Fivehook bassia (*Bassia hyssopifolia*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lambs quarters (*Chenopodium album*)	0.00	4.88	2.17	2.06	0.00	0.49	0.00	0.21
Brass buttons (*Cotula coronopifolia*)	50.00	46.34	19.57	29.90	16.92	0.39	0.01	1.77
Swamp timothy (*Crypsis schoenoides*)	30.00	24.39	15.22	17.53	0.77	4.86	2.03	3.13
Sedges (*Cyperus* spp.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salt grass (*Distichlis spicata*)	0.00	2.44	6.52	4.12	0.00	0.00	0.01	0.00
Watergrass (*Echinochloa crusgalli*)	30.00	29.27	39.13	31.96	0.08	9.56	23.37	15.20
Sunflower (*Helianthus* spp.)	0.00	2.44	0.00	1.03	0.00	0.01	0.00	0.00
Wild lettuce (*Lactuca* spp.)	0.00	4.88	8.70	6.19	0.00	0.00	0.00	0.00
Bird's foot trefoil (*Lotus corniculatus*)	0.00	0.00	4.35	2.06	0.00	0.00	0.00	0.00
Italian ryegrass (*Lolium multiflorum*)	10.00	0.00	10.87	3.09	0.01	0.00	9.98	4.73
Rice (*Oryza sativa*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bristly ox-tongue (*Picris echioides*)	0.00	14.63	15.22	13.40	0.00	0.00	0.00	0.00
Smartweed (*Polygonum* spp.)	10.00	12.20	8.70	10.31	0.00	0.02	1.40	0.67
Rabbit's foot grass (*Polypogon monspeliensis*)	60.00	34.15	15.22	27.84	0.69	0.22	0.00	0.16
Pondweed (*Potamogeton* spp.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dock (*Rumex* spp.)	0.00	14.63	15.22	12.87	0.00	0.03	0.53	0.26
Pickleweed (*Salicornia virginica*) seeds	30.00	51.22	17.39	31.96	0.09	1.93	0.09	0.88
Pickleweed (*Salicornia virginica*) stems	0.00	0.00	2.17	0.00	0.00	0.00	0.00	0.00
Bulrush (*Scirpus* spp.)	30.00	82.93	69.57	71.13	1.98	8.84	34.14	20.18
Sea purslane (*Sesuvium verrucosum*)	90.00	85.37	63.04	52.58	79.42	71.15	27.00	51.02
Black nightshade (*Solanum nigrum*)	0.00	2.44	0.00	1.03	0.00	0.00	0.00	0.00
Sow thistle (*Sonchus oleraceus*)	10.00	7.32	6.52	6.93	0.00	0.00	0.00	0.00
Salt marsh sand spurry (*Spergularia marina*)	0.00	7.32	0.00	3.09	0.00	0.00	0.00	0.00
Chickweed (*Stellaria media*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat (*Triticum aestivum*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cattail (*Typha* spp.)	20.00	2.44	0.00	3.09	0.00	0.00	0.00	0.00
Horned pondweed (*Zannichellia palustris*)	20.00	9.76	0.00	6.19	0.00	0.01	0.00	0.00
Corn (*Zea mays*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other seeds	10.00	4.88	4.35	4.95	0.00	0.05	0.00	0.02
Misc. vegetation	40.00	46.34	28.26	9.28	* no weights taken			
Grit	20.00	46.34	19.57	22.68	* no grit weights taken			

continued…

Table 4. Esophageal contents of green-winged teal (GW), northern pintails (NP) and mallards (MA) collected while actively feeding in the Suisun Marsh October-December 1997-98, 1998-99 (both years combined).

Table 4. Continued.

Invertebrates	% Occurrence				Aggregate % Dry Mass			
	GW	NP	MA	Total	GW	NP	MA	Total
Spiders (C. Arachnida)	10.00	2.44	6.52	5.15	* invertebrate biomass too low for weights			
Beetles (F. Carabidae)	0.00	0.00	6.52	3.09				
Midge larvae (F. Chironomidae)	40.00	24.39	32.61	28.87				
Leaf beetles (F. Chrysomelidae)	10.00	0.00	0.00	1.03				
Snout beetles (F. Curculionidae)	0.00	0.00	2.17	1.03				
Water boatmen (F. Corixidae)	10.00	0.00	13.04	7.22				
Plant hoppers (F. Dictyopharidae)	0.00	0.00	2.17	1.03				
Diving beetles (F. Dytiscidae)	10.00	4.88	13.04	9.28				
Brine flies (F. Ephydridae)	10.00	4.88	0.00	3.09				
Ants (F. Formicidae)	0.00	0.00	0.00	0.00				
Minute moss beetles (F. Hydraenidae)	0.00	0.00	2.17	1.03				
Water scavenger beetles (F. Hydrophilidae)	0.00	0.00	2.17	1.03				
Assassin bugs (F. Reduviidae)	0.00	0.00	2.17	1.03				
Bird lice (F. Menoponidae)	0.00	0.00	0.00	0.00				
Thrips (F. Phlaeothripidae)	0.00	0.00	0.00	0.00				
Rove beetles (F. Staphylinidae)	0.00	0.00	6.52	3.09				
Hover fly larvae (F. Syrphidae)	20.00	2.44	6.52	6.19				
Horse flies (F. Tabanidae)	0.00	0.00	2.17	1.03				
Crayfish (O. Amphipoda)	0.00	0.00	0.00	0.00				
Water fleas (O. Cladocera)	0.00	0.00	2.17	1.03				
Water flea eggs (O. Cladocera)	0.00	2.44	4.35	3.09				
Other beetle larvae (O. Coleoptera)	0.00	2.44	2.17	2.06				
Fly larvae (O. Diptera)	0.00	0.00	2.17	1.03				
Snails (O. Gastropoda)	0.00	2.44	6.52	4.12				
True bugs (O. Hemiptera)	10.00	0.00	2.17	2.06				
Termite (O. Isoptera)	0.00	0.00	4.35	2.06				
Seed shrimp (O. Ostracoda)	30.00	7.32	6.52	9.28				
False scorpion (O. Pseudoscorpiones)	0.00	0.00	0.00	0.00				
Other invertebrates	0.00	0.00	0.00	0.00				
Misc. fragments	0.00	34.15	15.22	14.43				

Table 5. Analysis of variation in esophageal contents (proportion of each food item in diet) in duck club and actively feeding birds. We tested differences among duck species and among seasons by Kruskal-Wallis one-way ANOVA. We tested differences among years by Mann-Whitney U-tests. We did not examine year and seasonal effects for ducks collected while actively feeding because we collected too few.

		Differences Among Species		Seasonal Differences (months)		Differences Among Years	
Duck Clubs		H *	*P*	H	*P*	z **	*P*
GW (n = 140)	Fat hen (*Atriplex triangularis*)	25.26	<0.01	26.3	<0.01	-0.18	>0.80
NP (n = 106)	Brass buttons (*Cotula coronopifolia*)	5.18	>0.07	8.4	<0.04	-2.41	<0.02
MA (n = 183)	Swamp timothy (*Crypsis schoenoides*)	0.24	>0.80	22.1	<0.01	-1.02	>0.30
	Watergrass (*Echinochloa crusgalli*)	31.47	<0.01	1.9	>0.50	-3.86	<0.01
	Smartweed (*Polygonum spp.)*	7.85	<0.02	2.4	>0.40	-1.05	>0.20
	Rabbit's foot grass (*Polypogon monspeliensis*)	3.57	>0.15	9.1	<0.03	-2.03	<0.05
	Dock (*Rumex spp*.)	4.57	>0.10	8.6	<0.04	-0.11	>0.90
	Pickleweed (*Salicornia virginica*)	22.98	<0.01	4.7	>0.15	-0.96	>0.30
	Bulrush (*Scirpus spp.)*	17.35	<0.01	1.3	>0.70	-0.06	>0.90
	Sea purslane (*Sesuvium verrucosum*)	8.94	<0.02	8	<0.05	-2.19	<0.03
Actively Feeding							
GW (n = 9)	Fat hen (*Atriplex triangularis*)	4.99	0.08				
NP (n = 39)	Brass buttons (*Cotula coronopifolia*)	11.01	<0.01				
MA (n = 38)	Swamp timothy (*Crypsis schoenoides*)	1.65	>0.40				
	Watergrass (*Echinochloa crusgalli*)	3.69	0.15				
	Smartweed (*Polygonum spp.)*	0.59	>0.70				
	Rabbit's foot grass (*Polypogon monspeliensis*)	8.99	<0.02				
	Dock (*Rumex spp*.)	1.66	>0.40				
	Pickleweed (*Salicornia virginica*)	10.21	>0.01				
	Bulrush (*Scirpus spp.)*	10.29	<0.01				
	Sea purslane (*Sesuvium verrucosum*)	12.53	<0.01				

* H = Kruskal-Wallis H statistic corrected for ties and associated *P*-values
** z = z-statistic from Mann-Whitney U-test corrected for ties and associated *P*-values

Table 6. Analysis of variation in esophageal contents (proportion of each food item in diet) in ducks collected during the day (actively feeding) compared to those collected when returning from night feeding (pass-shot). We tested differences between feeding and pass-shot birds by unpaired t-tests. Samples sizes: 9 feeding, 32 pass-shot (GW); 43 feeding, 48 pass-shot (MA); and 41 feeding, 35 pass-shot (NP).

	GW		NP		MA	
Food item	t*	*P*	t	*P*	t	*P*
Fat hen (*Atriplex triangularis*)	-1.99	>0.05	-0.86	>0.30	-1.15	>0.25
Brass buttons (*Cotula coronopifolia*)	2.67	<0.02	-0.68	0.50	0.30	>0.75
Swamp timothy (*Crypsis schoenoides*)	1.61	>0.10	-0.39	0.70	-0.96	>0.30
Watergrass (*Echinochloa crusgalli*)	-1.46	0.15	-2.61	<0.02	-1.82	0.07
Smartweed (*Polygonum spp.)*	-0.53	0.60	-1.72	0.09	-0.93	>0.35
Rabbit's foot grass (*Polypogon monspeliensis*)	-0.65	>0.50	-1.50	>0.10	0.10	>0.90
Dock (*Rumex spp*.)	-0.53	0.60	-1.12	>0.20	-0.32	0.75
Pickleweed (*Salicornia virginica*)	-1.51	>0.10	-0.32	>0.70	-0.81	>0.40
Bulrush (*Scirpus spp.)*	-0.56	>0.50	-2.49	<0.02	2.07	<0.05
Sea purslane (*Sesuvium verrucosum*)	3.34	<0.01	5.69	<0.01	0.95	0.35

* t = unpaired t-statistics and associated *P*-values. Negative t-values indicate the amount of a given food item was lower for day-feeding birds (F) than pass-shot (P) birds retuning from night feeding; positive t-values indicate the opposite.

Table 7. Analysis of food preferences for actively feeding birds. The percentage of each of the ten main food items in the diet (% diet), available at the feeding site (% avail) and the Forage Ratio (% diet / % avail) are shown. Paired t-tests were used to evaluate differences in the amount of each item in the diet relative to that available for each species. Wilcoxon Signed Ranks test provide a similar comparison, but ducks with zero values for a food item are excluded. The number of ducks of each species that exhibited a preference (rank of the difference [diet-avail] > 0), avoidance (rank < 0), or no preference are shown.

					Paired t-Test		Wilcoxon Signed-Ranks Test				
Species	Item	% Diet	% Avail	Forage ratio	t	*P*	z	*P*	#Ranks>0 (prefer)	#Ranks<0 (avoid)	#Ranks=0 (no pref)
GW	Brass buttons (*Cotula coronopifolia*)	16.94	2.51	6.75	1.69	0.13	0.89	0.37	4	5	0
(n=9)	Rabbit's foot grass (*Polypogon monspeliensis*)	0.69	0.05	13.80	1.58	0.15	0.98	0.33	5	3	1
	Sea purslane (*Sesuvium verrucosum*)	79.43	73.65	1.08	0.61	0.56	0.30	0.77	4	5	0
	Swamp timothy (*Crypsis schoenoides*)	0.77	0.76	1.01	0.41	0.69	0.13	0.89	3	2	4
	Smartweed (*Polygonum* spp.)	0.00	0.00	0.00	-0.89	0.40	-0.45	0.65	1	1	7
	Watergrass (*Echinochloa crusgalli*)	0.08	0.60	0.13	-0.98	0.35	0.00	1.00	2	1	6
	Pickleweed (*Salicornia virginica*)	0.09	1.39	0.06	-1.83	0.10	-1.21	0.22	2	3	4
	Bulrush (*Scirpus maritimus*)	1.98	16.07	0.12	-2.57	**0.03**	-1.84	0.07	3	6	0
	Fat hen (*Atriplex triangularis*)	0.02	5.02	0.00	-2.61	**0.03**	-2.03	**0.04**	0	5	4
	Dock (*Rumex* spp.)	0.00	0.00	0.00	-3.03	**0.02**	-2.02	**0.04**	0	5	4
NP	Sea purslane (*Sesuvium verrucosum*)	74.16	55.10	1.35	2.88	**0.01**	2.34	**0.02**	23	15	1
(n=39)	Fat hen (*Atriplex triangularis*)	2.57	1.37	1.88	0.46	0.65	-2.68	0.07	4	14	21
	Rabbit's foot grass (*Polypogon monspeliensis*)	0.23	0.14	1.64	0.43	0.67	0.09	0.93	13	10	16
	Swamp timothy (*Crypsis schoenoides*)	2.62	3.16	0.83	-0.16	0.88	-0.72	0.47	7	9	23
	Watergrass (*Echinochloa crusgalli*)	9.38	10.76	0.87	-0.80	0.43	-0.74	0.46	6	9	24
	Bulrush (*Scirpus maritimus*)	8.54	15.60	0.55	-1.46	0.15	-0.90	0.37	20	16	3
	Brass buttons (*Cotula coronopifolia*)	0.41	3.16	0.13	-1.87	0.07	-2.09	**0.04**	7	23	9
	Dock (*Rumex* spp.)	0.03	0.86	0.03	-2.03	**0.05**	-1.96	**0.05**	4	8	27
	Smartweed (*Polygonum* spp.)	0.02	0.15	0.13	-2.12	**0.04**	-1.86	0.06	5	9	25
	Pickleweed (*Salicornia virginica*)	2.03	10.73	0.19	-3.15	**<0.01**	-4.24	**<0.01**	5	23	11

Continued …

Table 7. Continued.

Species	Item	% Diet	% Avail	Forage ratio	Paired t-Test		Wilcoxon Signed-Ranks Test				
					t	*P*	z	*P*	#Ranks>0 (prefer)	#Ranks<0 (avoid)	#Ranks=0 (no pref)
MA	Watergrass (*Echinochloa crusgalli*)	25.14	11.76	2.14	2.93	**0.01**	2.26	**0.02**	17	10	11
(n=38)	Bulrush (*Scirpus maritimus*)	38.87	25.67	1.51	1.77	0.09	1.34	0.18	21	16	1
	Rabbit's foot grass (*Polypogon monspeliensis*)	1.20	0.19	6.32	0.88	0.39	-1.89	0.06	5	14	19
	Swamp timothy (*Crypsis schoenoides*)	2.26	1.59	1.42	0.28	0.78	-2.46	**0.01**	5	14	19
	Dock (*Rumex* spp.)	0.67	1.11	0.60	-0.64	0.53	-1.41	0.16	4	10	24
	Sea purslane (*Sesuvium verrucosum*)	31.36	35.61	0.88	-0.78	0.44	-0.75	0.46	16	21	1
	Smartweed (*Polygonum* spp.)	0.01	1.19	0.01	-1.53	0.13	-2.80	**0.01**	3	11	24
	Brass buttons (*Cotula coronopifolia*)	0.37	3.24	0.11	-1.58	0.12	-2.76	**0.01**	5	15	18
	Fat hen (*Atriplex triangularis*)	0.02	4.39	0.00	-2.35	**0.02**	-3.21	**<0.01**	3	13	22
	Pickleweed (*Salicornia virginica*)	0.10	15.25	0.01	-4.06	**<0.01**	-4.62	**<0.01**	0	28	10

Table 8. Analysis of food preferences for actively feeding ducks. For each species, preference was measured as the difference in the proportion of a food item used and the proportion of that item available at the site where the bird was collected. Significant variation in preferences for different food items was tested by Friedman's Rank Test.

	Species					
	GW		NP		MA	
Overall Test of Preference [a]	χ^2 = 5.01, P = 0.37		χ^2 = 22.49, P < 0.008		χ^2 = 42.3, P < 0.0001	
Food item	Mean rank [b]	Rank [c]	Mean rank	Rank	Mean rank	Rank
Fat hen (*Atriplex triangularis*)	3.61	8	5.05	8.5	5.13	9
Brass buttons (*Cotula coronopifolia*)	5.44	4.5	5.05	8.5	5.72	4
Swamp timothy (*Crypsis schoenoides*)	6.17	1	5.82	4	5.92	3
Watergrass (*Echinochloa crusgalli*)	5.44	4.5	5.35	7	6.66	1
Smartweed (*Polygonum* spp.)	5.50	3	5.62	5	5.63	6
Rabbit's foot grass (*Polypogon monspeliensis*)	5.72	2	6.04	2	5.59	7
Dock (*Rumex* spp.)	- [d]	-	5.55	6	5.66	5
Pickleweed (*Salicornia virginica*)	4.78	6	3.99	10	2.91	10
Bulrush (*Scirpus* spp.)	3.44	9	5.87	3	6.22	2
Sea purslane (*Sesuvium verrucosum*)	4.89	7	6.67	1	5.55	8

[a] The overall test of preference examines whether the ranked differences in food use versus availability (d) vary significantly among food items. The test statistic is χ^2 with G-1 degrees of freedom where G is the number of food items considered (G = 10 for MA and NP, G = 9 for GW)

[b] Mean rank is the average rank of the difference (d) between the amount of each food item used relative to its availability. Higher values indicate a greater degree of preference.

[c] Rank is the ordinal rank of each food item for each species, arranged from most preferred (1) to least preferred (10)

[d] Preference for all 10 food items could not be examined for green-winged teal since only 9 birds were collected; Rumex was eliminated from the analysis given its low level of use.

Table 9. Dabbling duck food item preferences* relative to ranked seed sizes and body size.

Increasing body size →

↓ Increasing seed size

FOOD ITEM	green-winged teal	northern pintail	mallard
SEA PURSLANE	1	1	3
FAT HEN	2	5	7
SMARTWEED	9	6	6
BULRUSH	6	3	2
WATERGRASS	3	2	1

*ranked 1-10 based on aggregate % dry mass in diet

Figure 1. The Suisun Marsh study area.

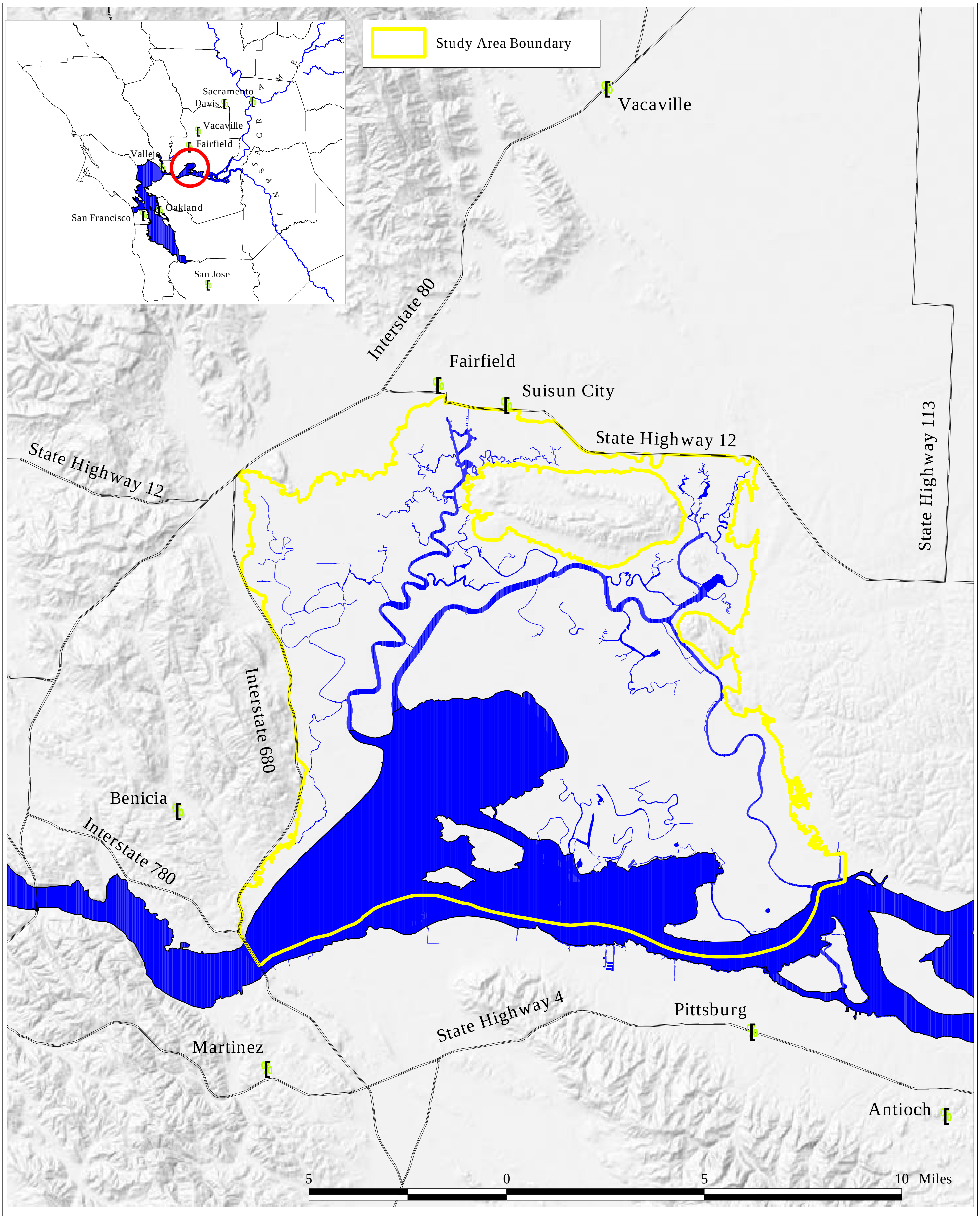


Figure 2. Collection locations for actively feeding ducks within the Suisun Marsh.

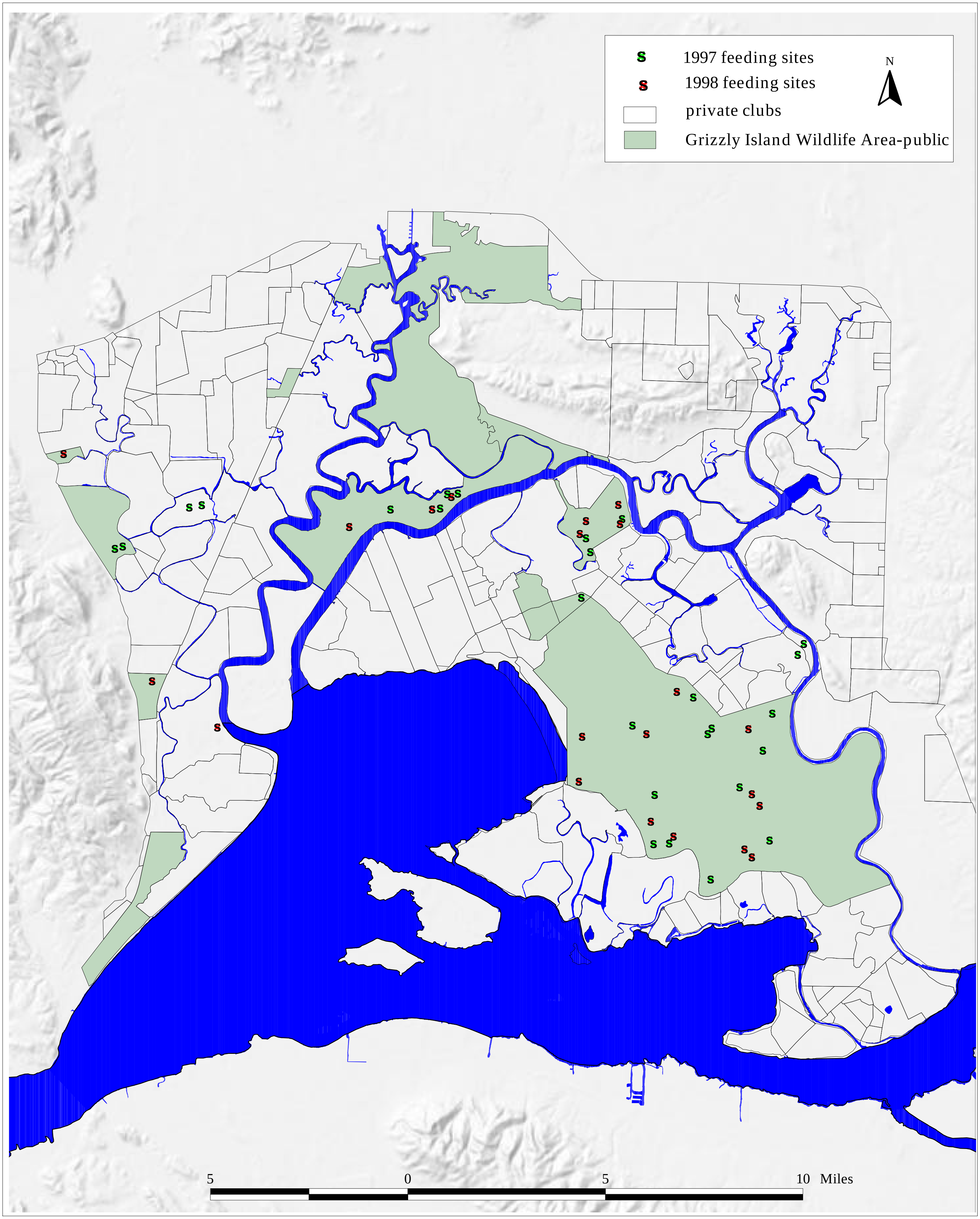


Figure 3. Private duck clubs within the Suisun Marsh that contributed ducks for food habits analyses.

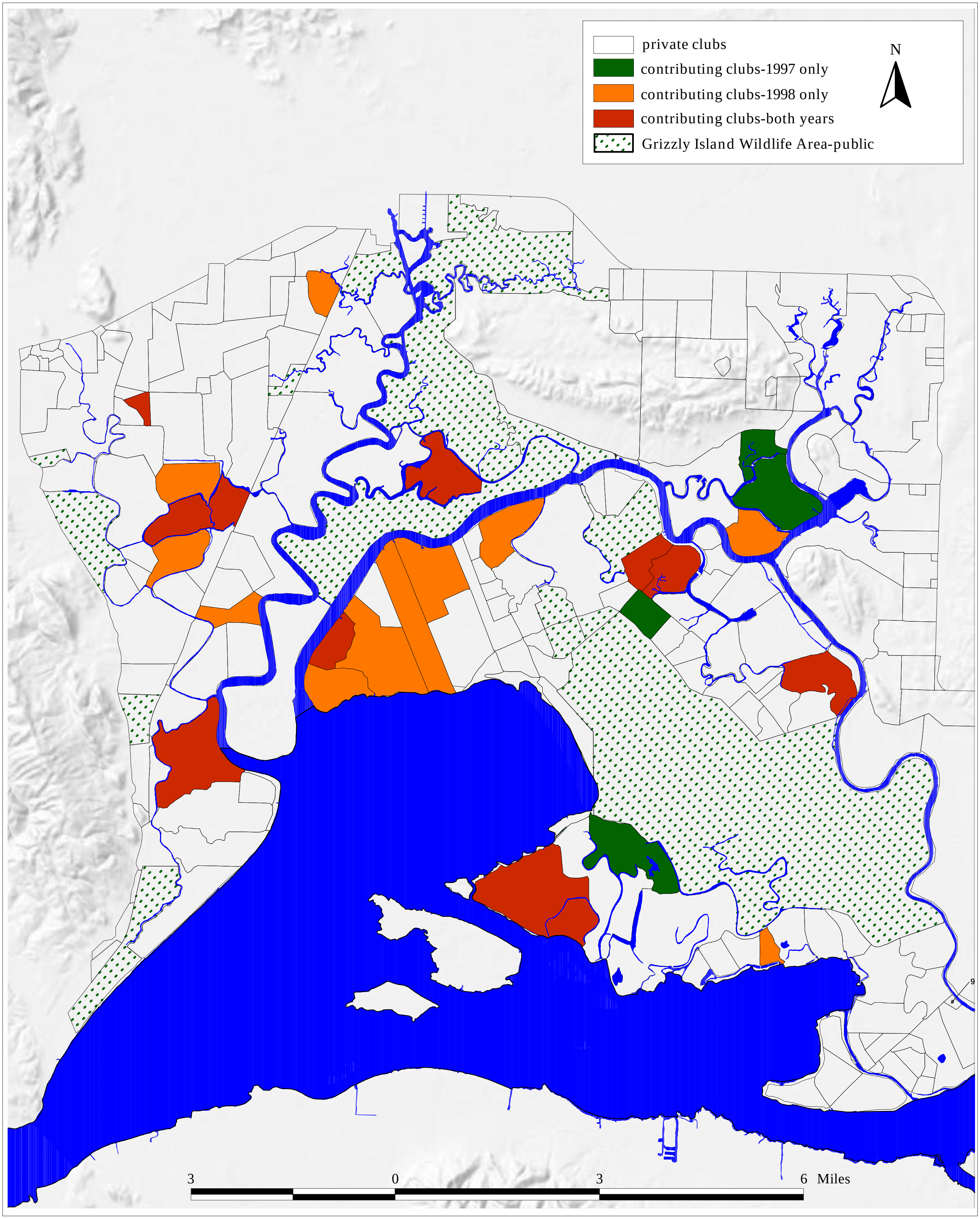


Figure 4. Frequency of occurrence of top ten food items of ducks shot at duck clubs October-January 1997-98 and 1998-99.

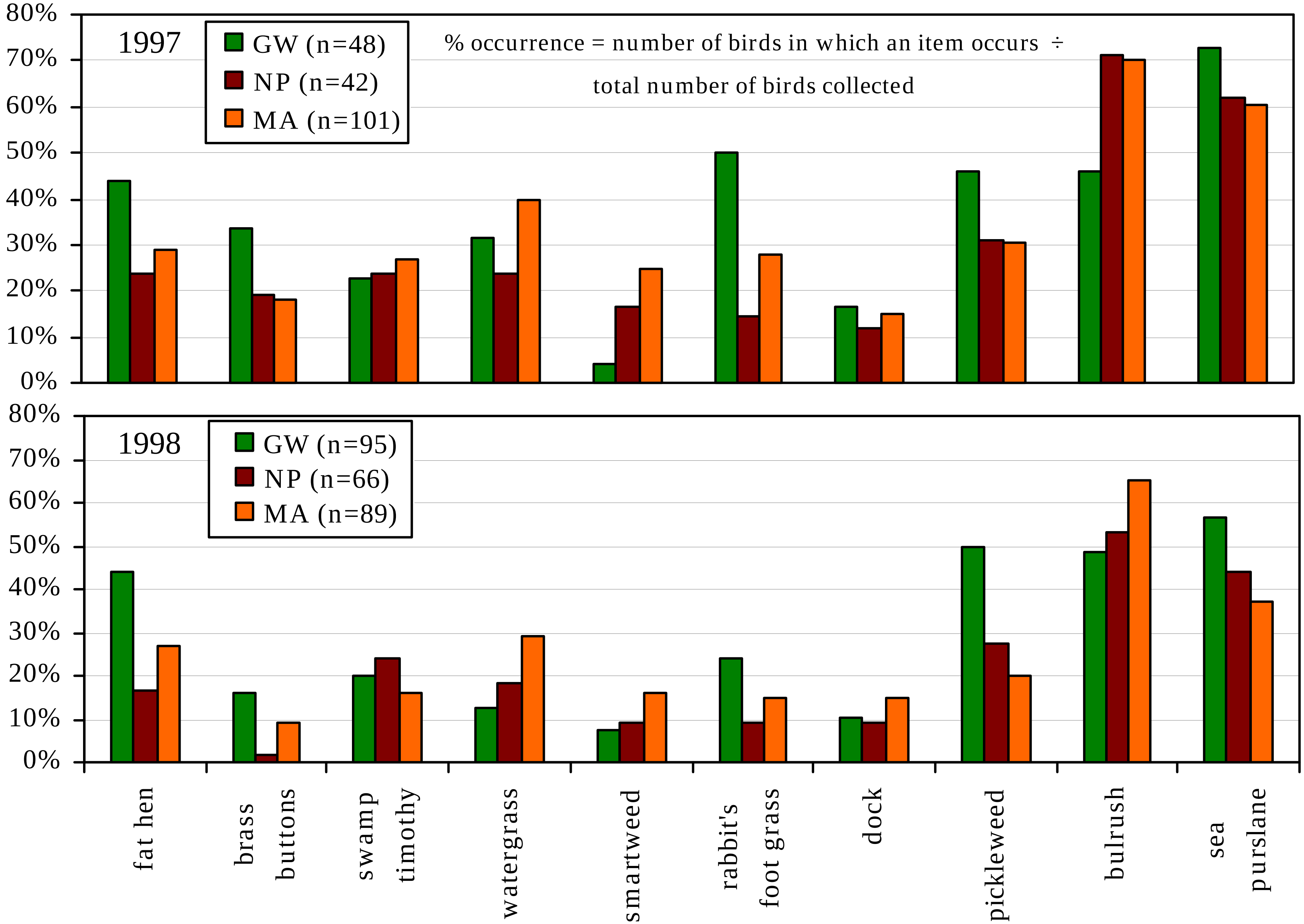


Figure 5. Frequency of occurrence of top ten food items of pass-shot ducks September-December 1997 and 1998.

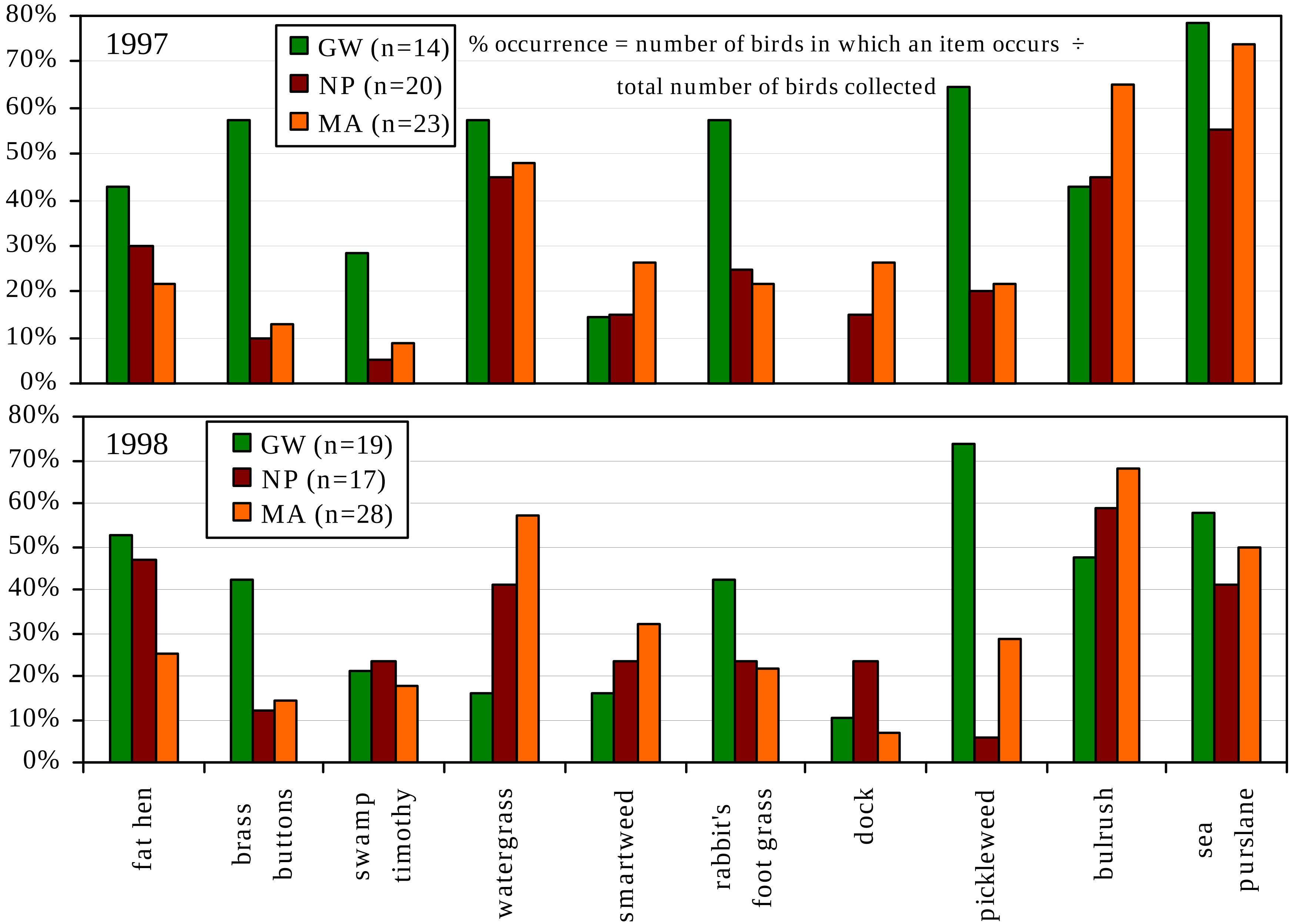


Figure 6. Frequency of occurrence of top ten food items of actively feeding ducks September-December 1997 and 1998.

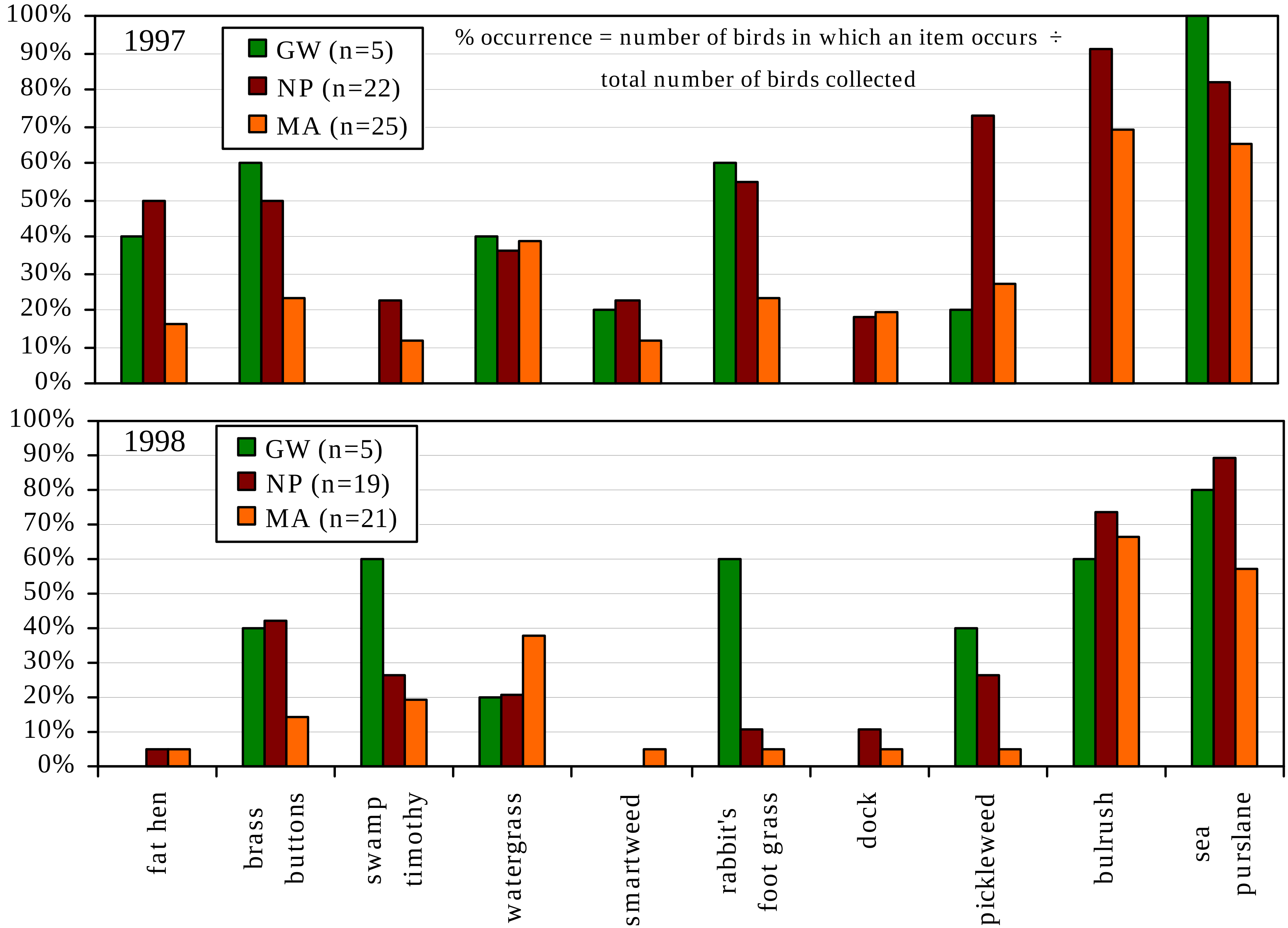


Figure 7. Aggregate % dry mass of top ten food items of ducks shot at duck clubs October-January 1997-98 and 1998-99.

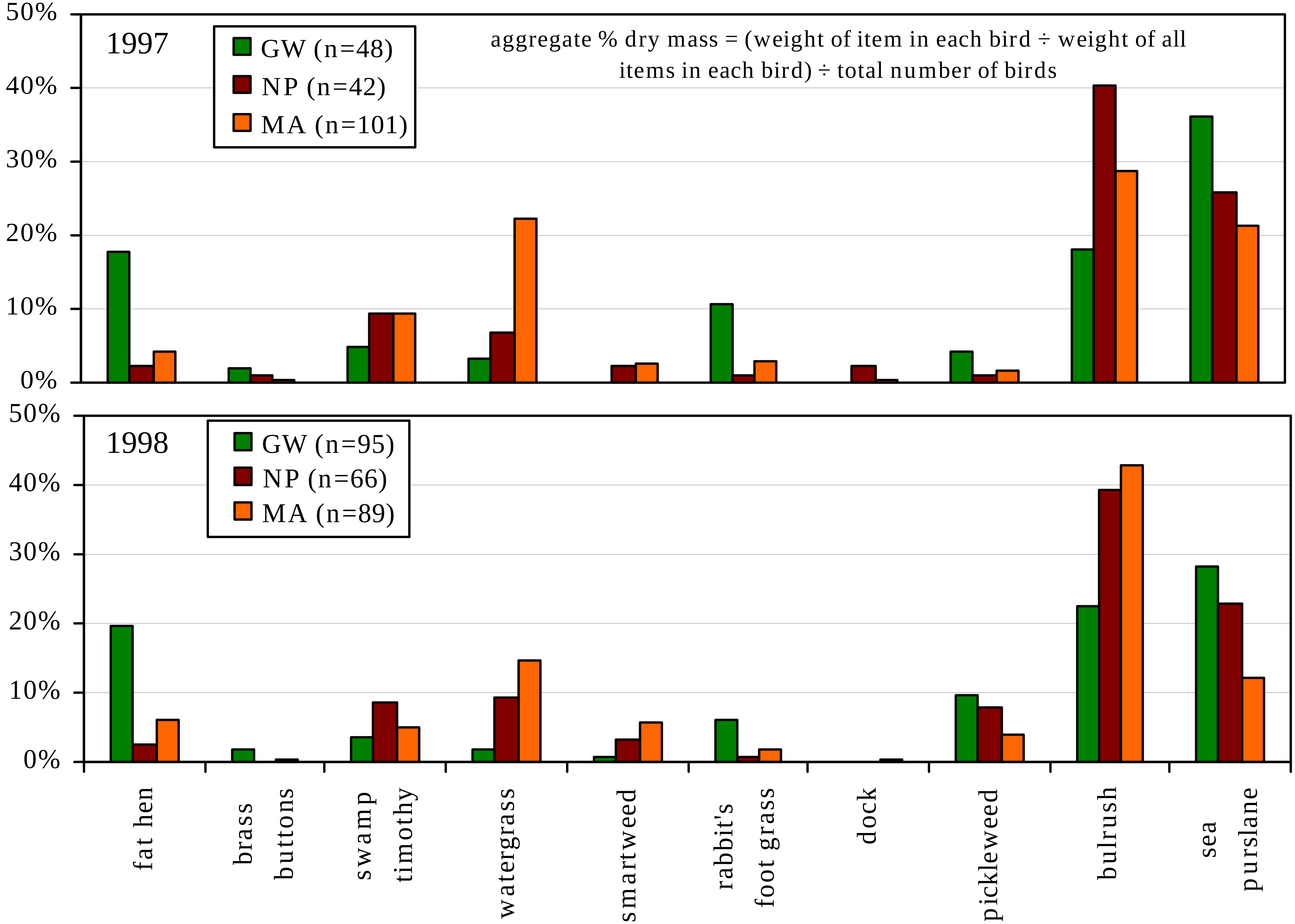


Figure 8. Aggregate % dry mass of top ten food items of pass-shot ducks September-December 1997 and 1998.

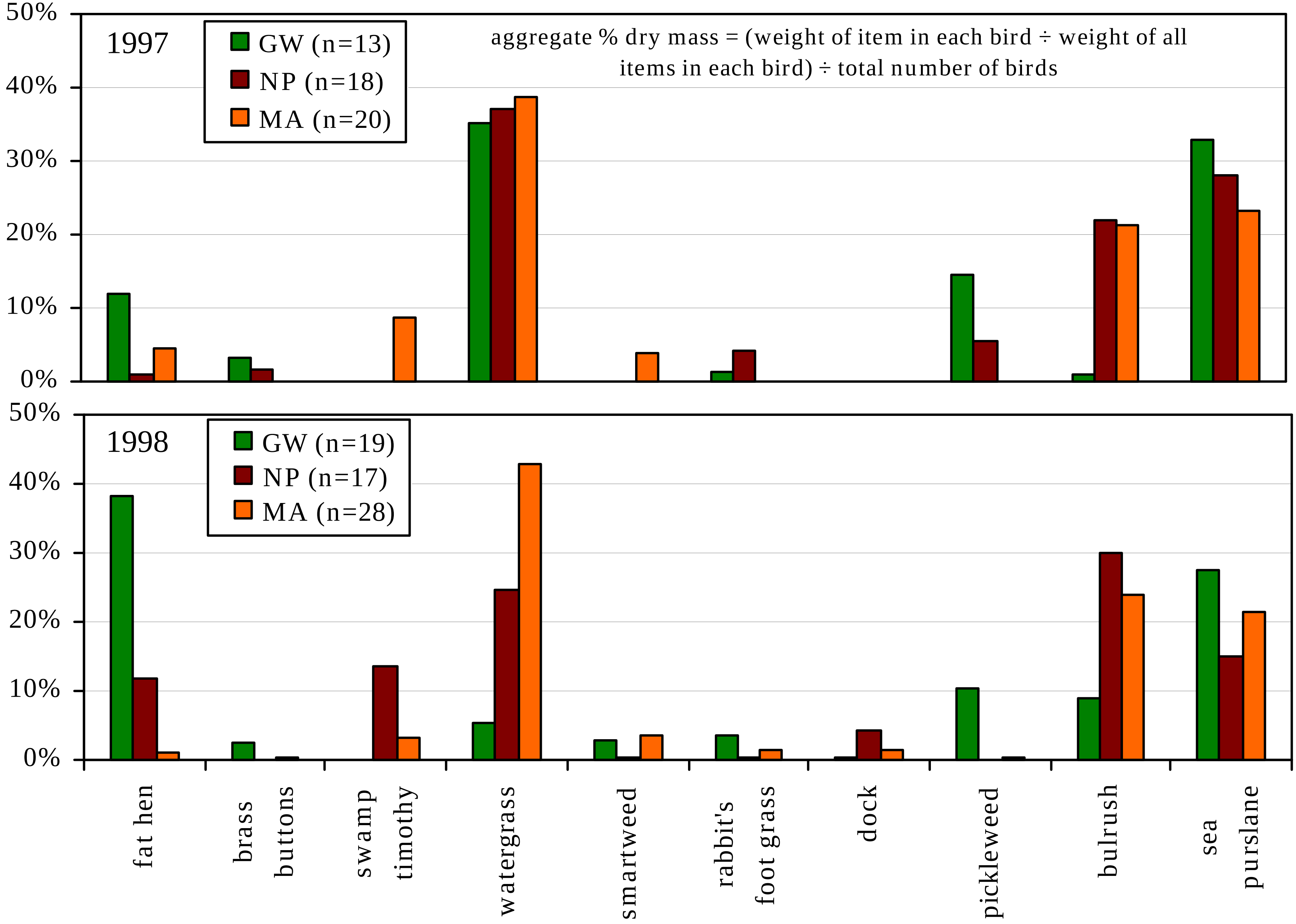


Figure 9. Aggregate % dry mass of top ten food items of actively feeding ducks September-December 1997 and 1998.

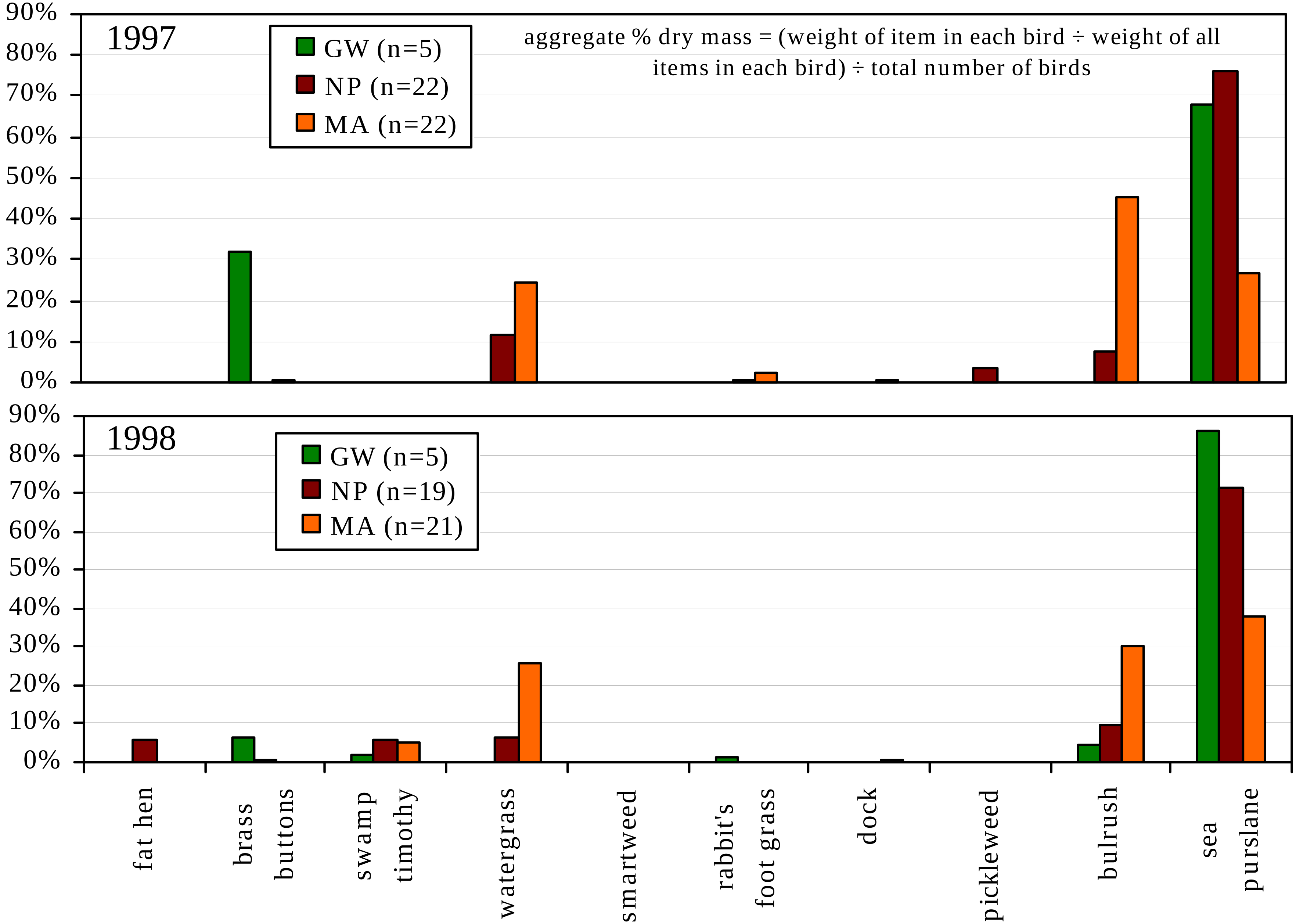


Figure 10. Seasonal trends in consumption of important food items recorded in ducks shot at Suisun Marsh clubs 1997-99.

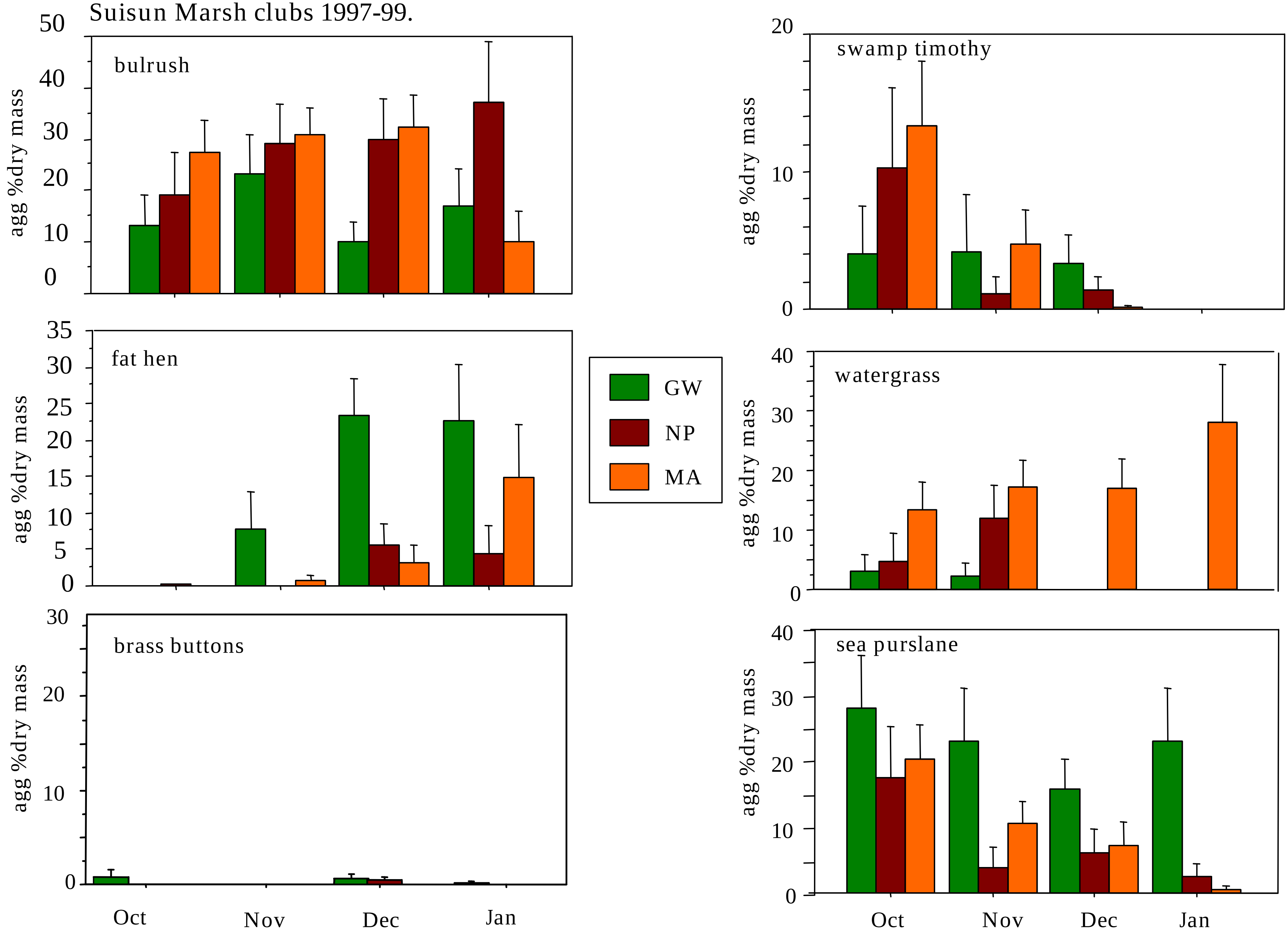


Figure 11. Proportion of foods available at feeding sites vs. proportion in diet of actively feeding green-winged teal.

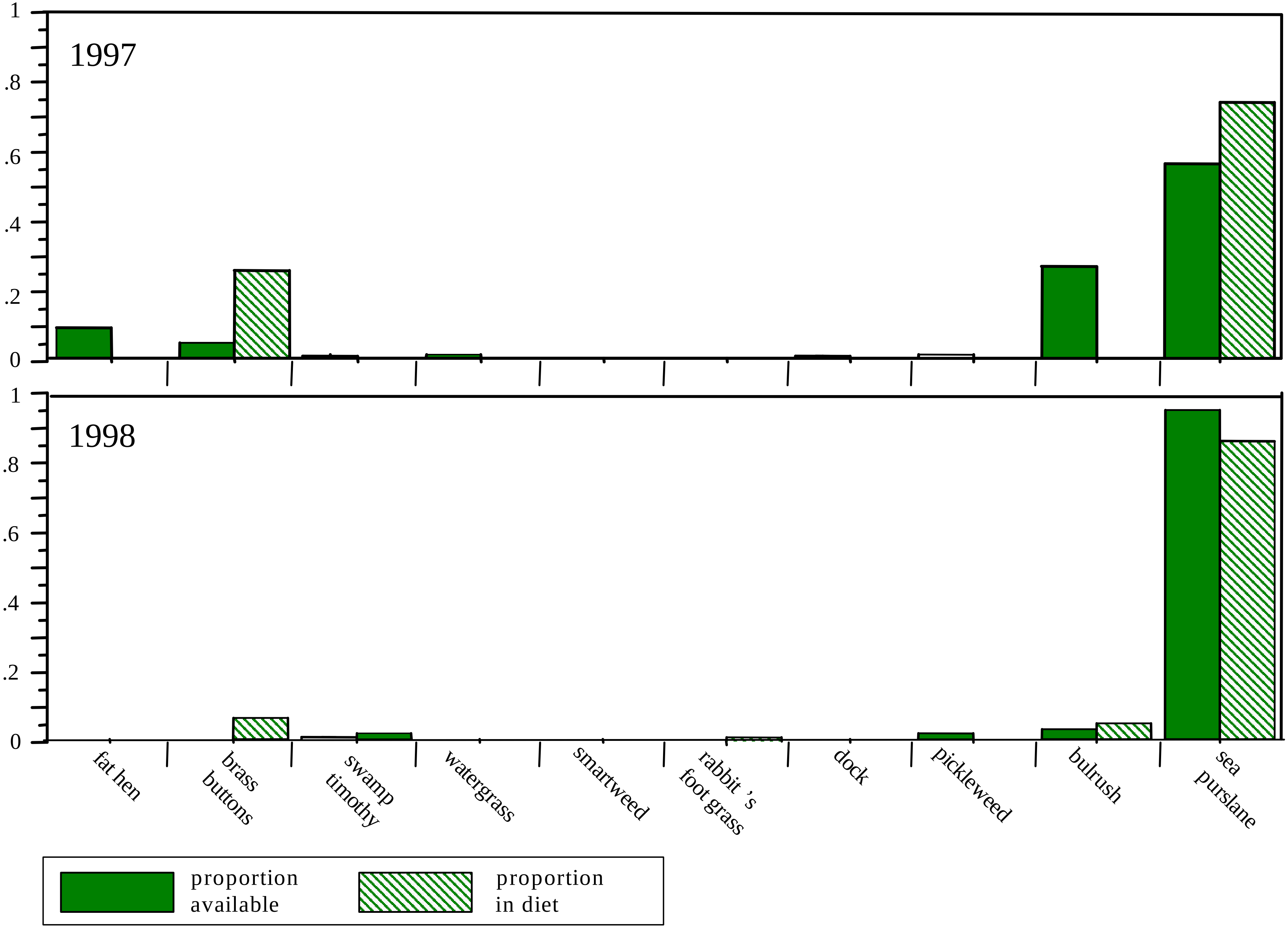


Figure 12. Proportion of foods available at feeding sites vs. proportion in diet of actively feeding northern pintails.

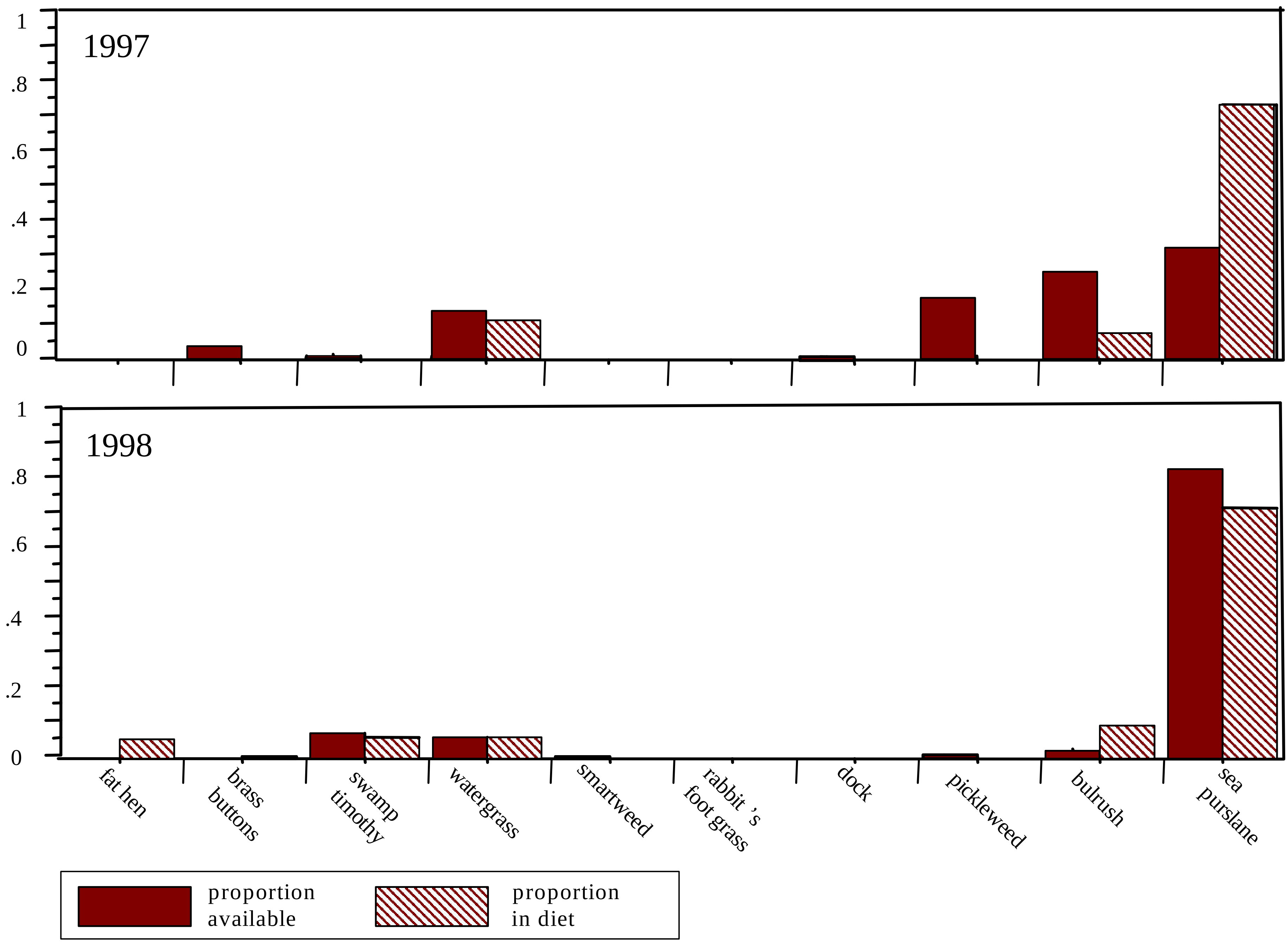


Figure 13. Proportion of foods available at feeding sites vs. proportion in diet of actively feeding mallards.

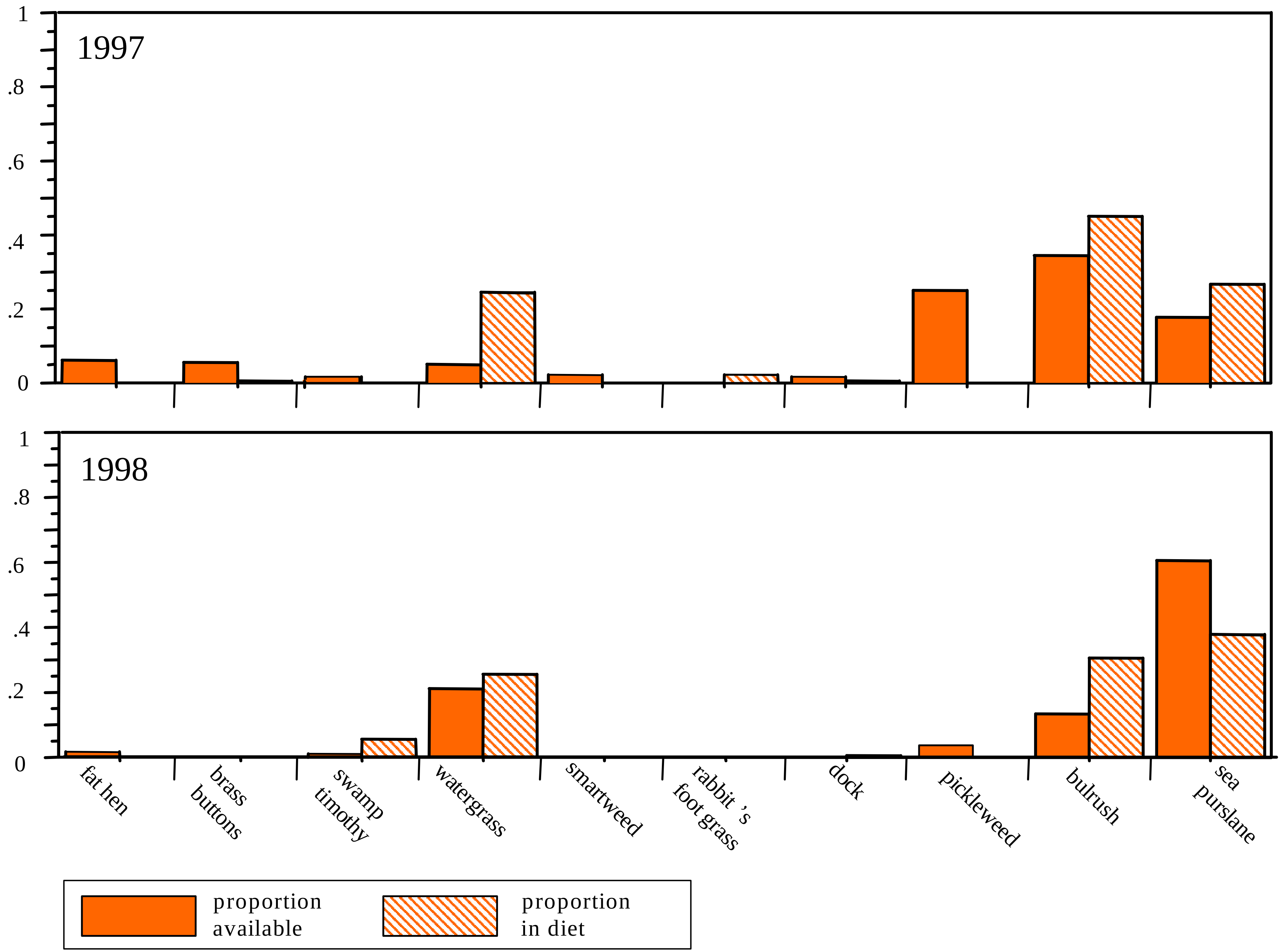


Figure 14. Box plots of differences between foods consumed by actively feeding ducks and their proportional availability at feeding sites for bulrush, watergrass, swamp timothy and sea purslane.
preference = +   avoidance = -

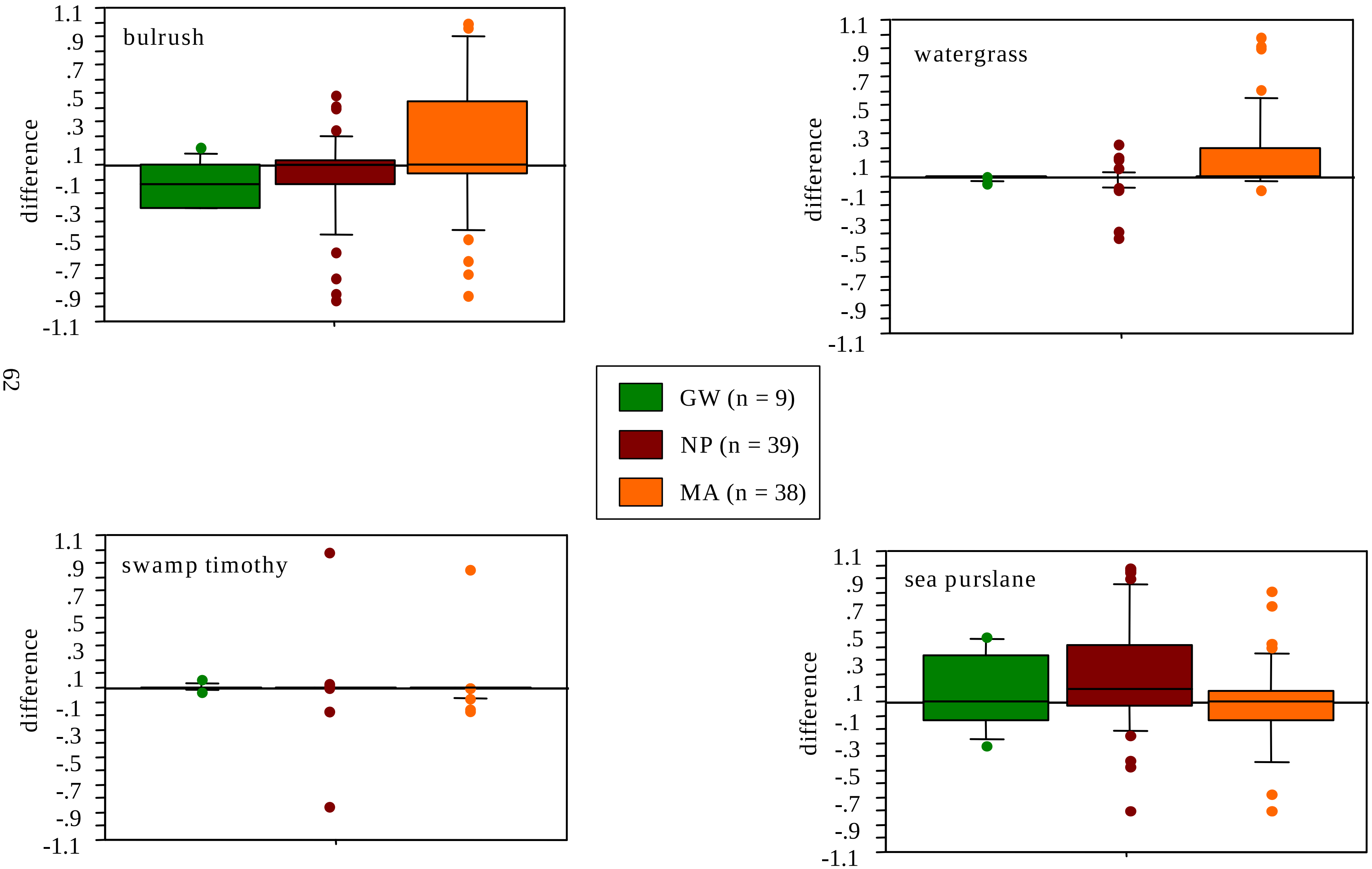


Figure 15. Box plots of differences between foods consumed by actively feeding ducks and their proportional availability at feeding sites for fat hen, brass buttons, dock and pickleweed.
preference = + avoidance = -

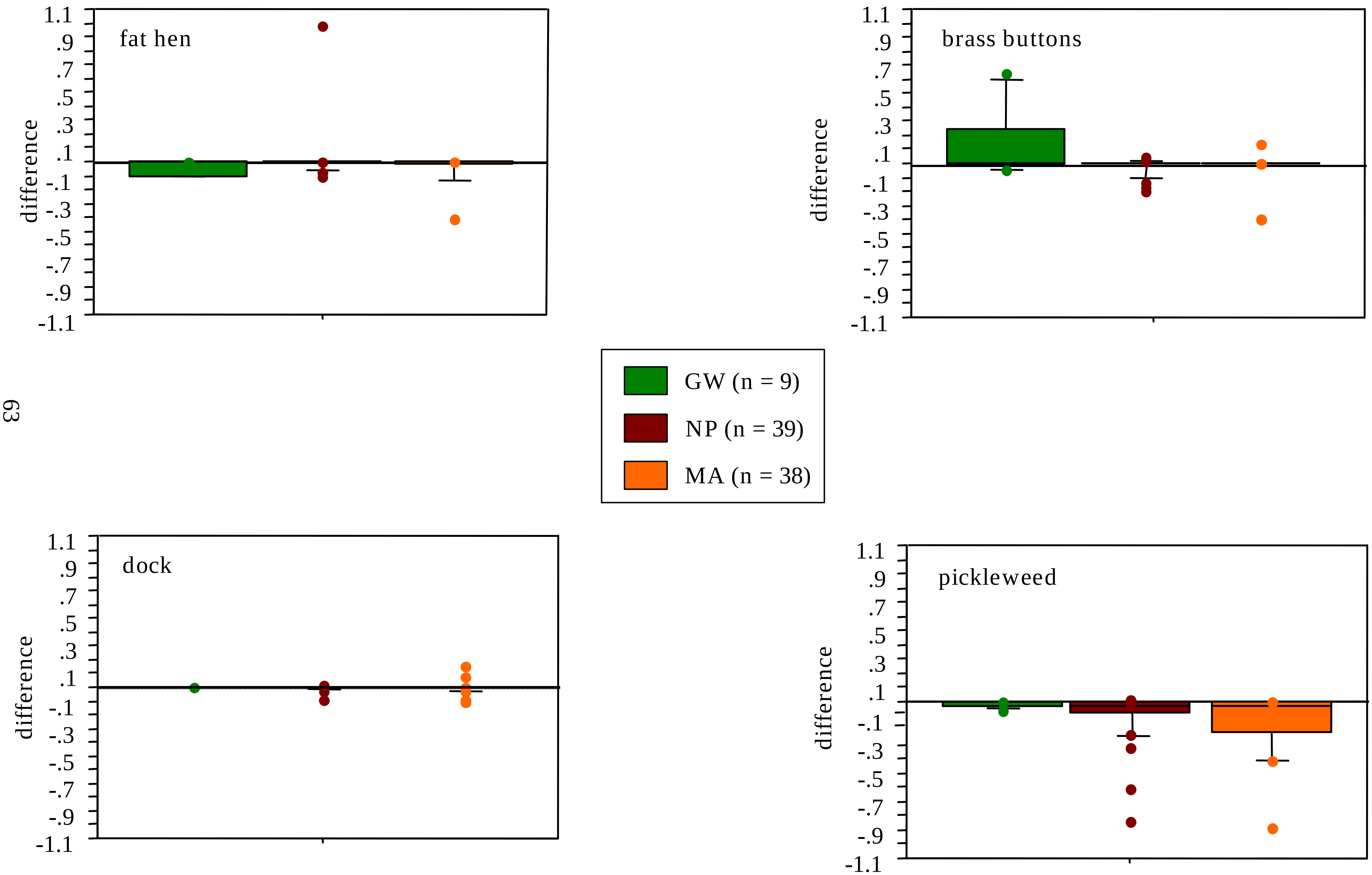


Figure 16. Proportions of four major food items in esophagi and gizzards of actively feeding ducks collected in the Suisun Marsh in 1998.

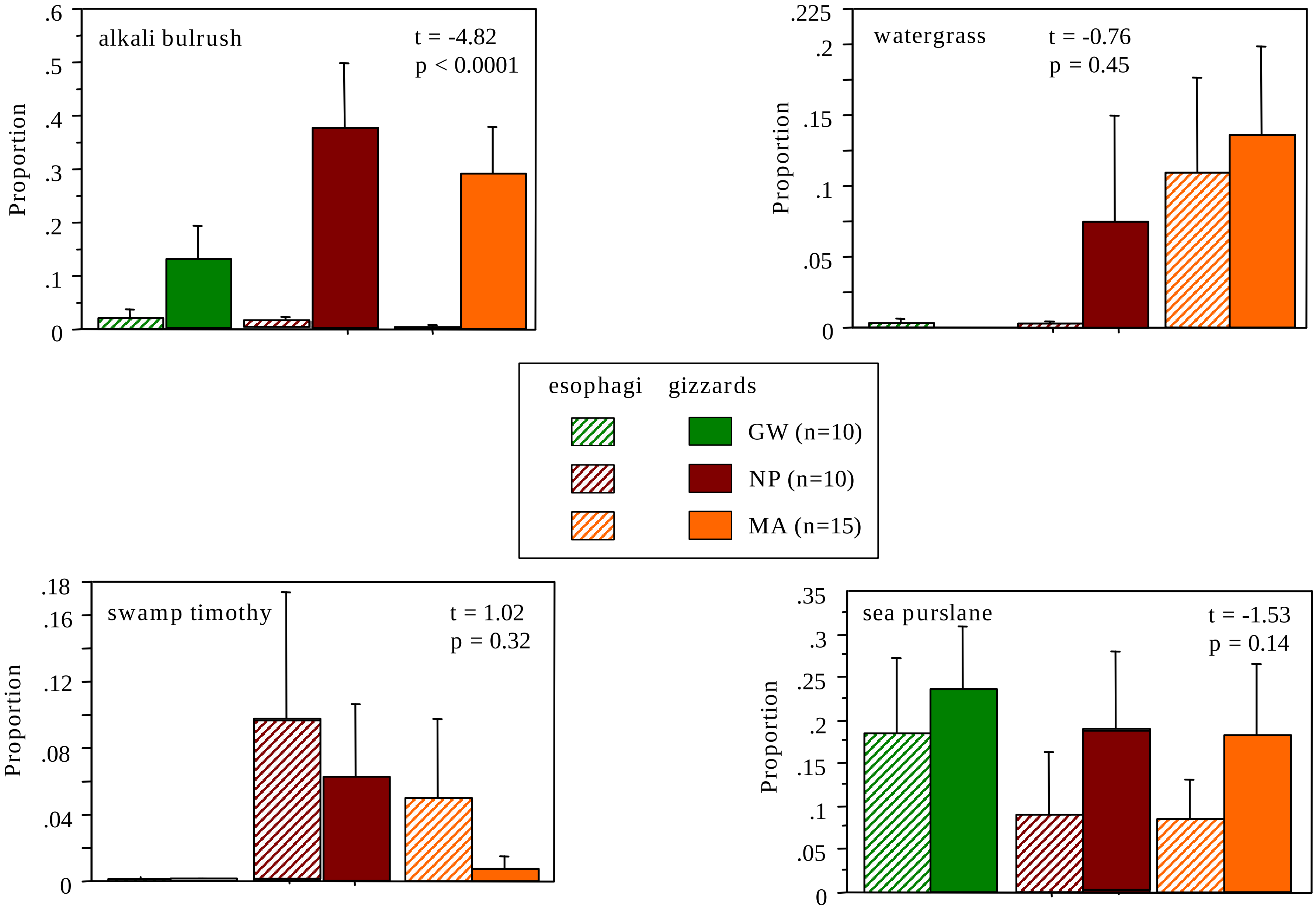


Figure 17. Seasonal trends in gizzard contents of ducks shot in the Suisun Marsh 1960-61.

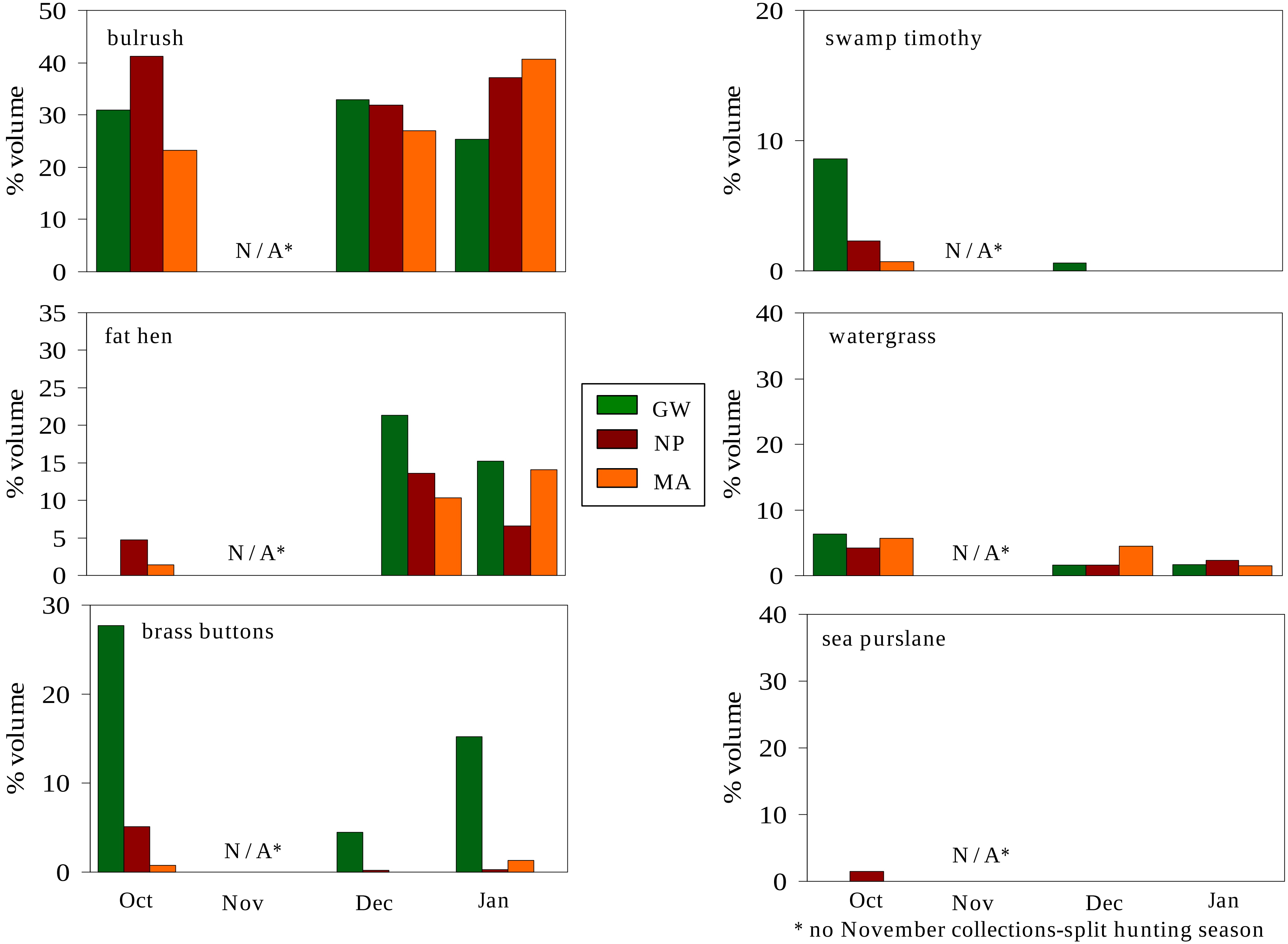
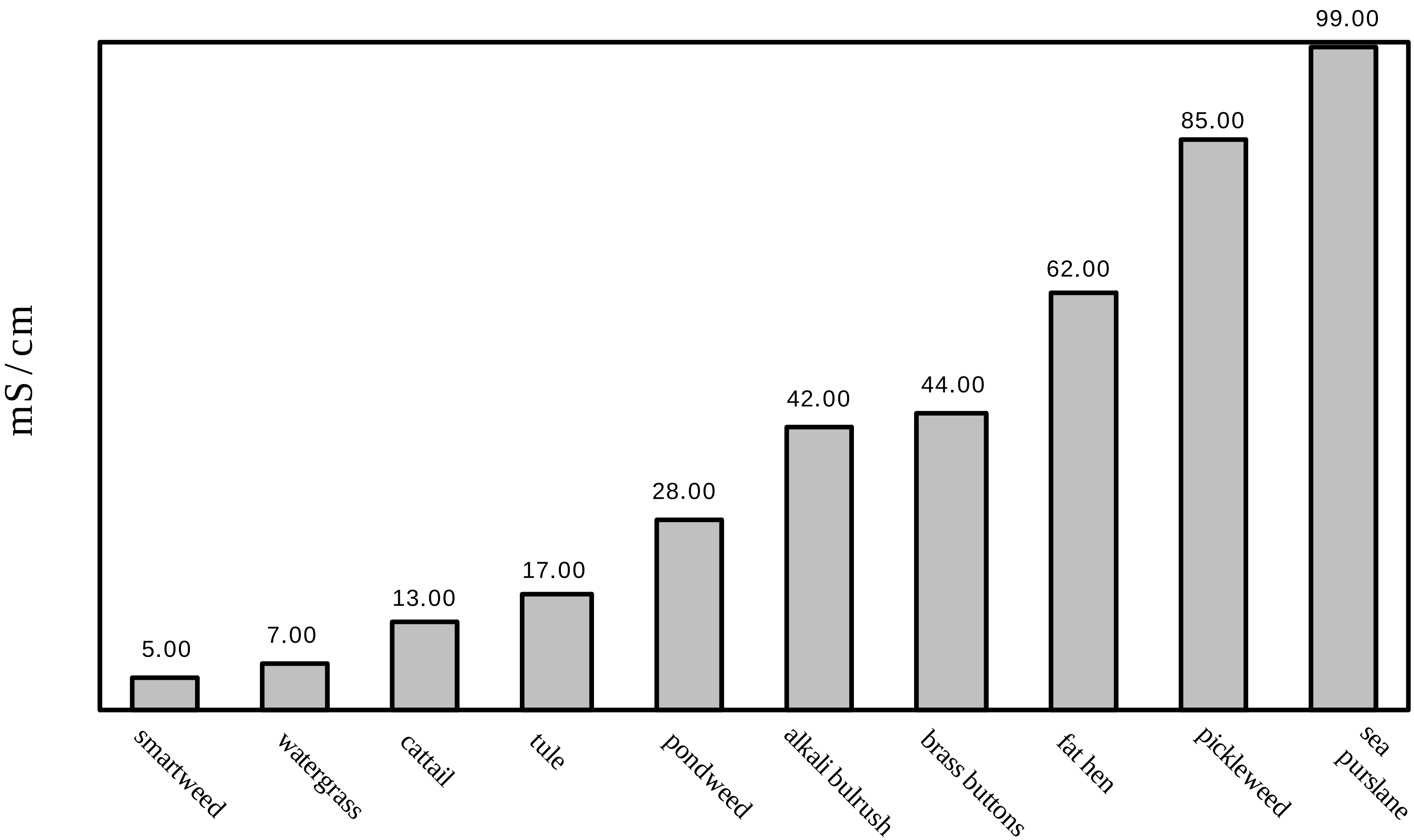


Figure 18. Soil salinity ranges and ranks of common Suisun Marsh plants in duck diets.



rank in diet

GW	9	3				6	5	2	4	1
NP	10	2				3	9	5	6	1
MA	6	1				2	13	7	10	3

(agg % dry mass for feeding and pass-shot birds combined)